UNIVERSITY OF TORONTO
3 1761 00352787 6

THE
MANUFACTURE OF IRON
IN
GREAT BRITAIN.

BY GEORGE WILKIE.

~~H. 37.~~

Board of Arts & Manufactures
for Upper Canada
1861.

DEPARTMENT OF MINING ENGINEERING
Library Number
[illegible]
[illegible]
Date
All [illegible]
[illegible]
[illegible]
[illegible]

Section C4
No 173

DEPARTMENT OF MINING ENGINEERING
MEi 122
[illegible]

THE

MANUFACTURE OF IRON

IN

GREAT BRITAIN.

PUBLIC WORKS
LIBRARY

THE

MANUFACTURE OF IRON

IN

GREAT BRITAIN;

WITH REMARKS

ON THE EMPLOYMENT OF CAPITAL IN IRON-WORKS
AND COLLIERIES.

By GEORGE WILKIE, Assoc. Inst. C.E.,
CIVIL ENGINEER.

97417 —
6/5/09

A. FULLARTON & CO.,
STEAD'S PLACE, LEITH WALK, EDINBURGH,
AND 106 NEWGATE STREET, LONDON.

1857.

TN
704
G7W5

PREFACE.

HAVING, during several years' experience in the Iron Trade and Manufacture, frequently observed the heavy losses incurred by capitalists investing in that branch of manufacture, such losses often arising from want of practical knowledge of the subject, I have, in the following pages, endeavoured, however indifferently I may have succeeded, to give a succinct and clear view of the main principles and practice of the manufacture of Iron, as at present conducted in this country, and also to point out the chief causes that usually prevent such undertakings from being conducted to a successful issue.

G. W.

LONDON, 1*mo.* 8*th*, 1857.

CONTENTS.

THE

MANUFACTURE OF IRON.

HISTORICAL SKETCH.

THE manufacture of iron was practised in Britain at the time of the Roman invasion, and probably long before that period; indications that the outcrops or basset edges of deposits of ironstone have been worked at some remote period, may be seen at the present day in many places,—and in some instances the rich scoria or cinder of ancient operatives has been reworked by more recent manufacturers.*

Iron was a branch of manufacture carried on to some extent in numerous localities. At the time of the Norman invasion, the city of Gloucester was the seat of a considerable manufacture of iron; but, until the use of fossil coal for manufacturing iron was introduced, Sussex, and to some extent the adjoining counties of Surrey and Kent, may be considered to have been a principal seat of manufacture.

Under the head of 'Sussex,' Fuller, in his 'Worthies of England,' written in 1662, makes the following remarks:—

---

* "In the Forest of Dean, in Gloucestershire, the best iron-ore is of a bluish colour, and is called 'brush-ore;' but this being melted alone, produces a metal very short and brittle; to remedy which inconvenience they make use of cinder, which is found in great quantity where any old works have been in that county: for in former times, their bellows being moved only by hand, their furnaces produced a fire much less intense than those they now employ; so that formerly they melted down only the principal part of the ore, rejecting the rest as useless. This refuse is the cinder, which being mingled with the ore in a due quantity, gives that excellent temper of toughness, for which this iron is preferred before any brought from abroad."—*Lexicon Technicum, by Dr. Harris.*

"Great the quantity of iron made in this county, whereof much used therein, and more exported thence into other parts of the land, and beyond the seas. It is almost incredible how many great guns are made of the iron in this county. Count Gondomer well knew their goodness, when of King James he so often begg'd the boon to transport them.

"A monke of Mentz (some three hundred years since) is generally reputed the first founder of them.

"Anno 1535. John Oaven was the first Englishman, who, in England, cast brass ordnance, cannons, culverings, &c.

"Peter Baud, a Frenchman, in the first of King Edward the Sixth [1547], was the first who, in England, cast iron-ordnance, falcons, falconers, minions, &c.

"Thomas Johnson, covenant-servant to Peter aforesaid, succeeded and exceeded his master, casting them clearer and better. He died about 1600."

In reference to the increasing scarcity and dearness of timber for charring, and the desirableness of providing a substitute, Fuller remarks:

"It is to be hoped, that a way may be found out, to charke seacole in such manner, as to render it useful for the making of iron. All things are not found out in one age, as reserved for future discovery, and that perchance may be *easy* for the next which seems *impossible* to this generation."

The last charcoal furnace in Sussex was blown out about the year 1815. It was in the parish of Dallington, and was commonly called Ashburnham Furnace. Dallaway, in his 'History of Western Sussex,' states that there "are mineral beds of lime and ironstones to the depth of 120 feet near Ashburnham furnace.* The iron and lime stones generally rise within three feet of the surface. To make thirteen tons of pig iron it requires 50 loads of charcoal (two cords of wood make one load of charcoal, and two of these a weighing load), and 50 loads of ironstone, 12 bushels to each load."

---

* Dr. Mantell places the Ashburnham beds in the lower group of the Wealden Formation, and describes them as consisting of alternations of friable sandstone, shale, sand and clay, mostly ferruginous, and enclosing rich argillaceous iron ore, beds of shelly limestone, shale, grit, &c.

Dr. Horsfield, in his 'History of Sussex,' mentions that Ashburnham Forge, (in the parishes of Ashburnham and Penhurst,) the last of the iron-works in the eastern division of the county, ceased working about 1827.

A large iron foundry was very anciently established at Fernhurst in Sussex, and was employed by government about 1765 for the casting of cannon.

Composition for the tythe of iron ore in the parish of Lynch in West Sussex, is mentioned in 1342.

The destruction of large timber for preparing charcoal for the use of the iron-works had, at various times, but especially during the 16th century, attracted the serious attention of the government, and many enactments were framed by the Legislature in order to prevent the rapid destruction of the woods, amongst which may be mentioned :—

Act 1 Elizabeth, c. 15. [1558] Relating to the Felling of Timber.
,, 5 do. [1562] for the Preservation of Woods near the Southdowns.
,, 23 do. c. 5. [1580] for Restraining the Iron-Mills.
,, 27 do. c. 19. [1584] for the same.
,, 8 James I., [1610] for the Preservation of Woods in Kent, Surrey, and Sussex,—amending the act of 35th Henry VIII. [1543] c. 17, for the same purpose.

It appears that James the First, in the 19th year of his reign [1621], granted a patent to Dud Dudley for making iron with fossil coal; and that Charles the First, in the 14th year of his reign [1638], granted another patent to him for the same purpose,—and from Dudley's very interesting account of his own proceedings given in his 'Metallum Martis,' (printed in 1665,*) it seems that after a variety of difficulties and mishaps he succeeded in producing seven tons of iron per week from one furnace in the parish of Sedgley in Staffordshire. The cast-iron he made was of three qualities.—"The first sort," he says, "is grey iron; the second sort is called motley iron, of which one part of the sows or pigs is grey, the other part is white intermixed; the third sort is called white iron;

---

* Recently re-published by Longman & Co., London. Price 2s. 6d.

this is almost as white as bell metal, but in the furnace is least fined, and the most terrestrial."

He also mentions that he made good profit by the sale of pig iron at £4 per ton, and bar-iron at £12 per ton and under, made with pit-coal, in the twentieth year of James's reign [1622], charcoal bar-iron being then from £15 to £18 per ton. He also mentions both the great consumption of timber then taking place for charcoal for iron-making, and condemns the wasteful working of the South Staffordshire ten-yard coal.

Notwithstanding that Lord Dudley succeeded in using coal instead of wood for fuel in making iron, and that he complains of his invention being pirated by some other iron manufacturers from the time of his first introducing it in 1618, still very little progress seems to have been made in the use of coal for iron smelting till nearly a century afterwards, when it was re-introduced in 1713 by Abraham Darby, in his furnace at Colebrookdale in Shropshire.

From the end of the 16th century, when the supply of wood for the manufacture of charcoal in the iron-making districts had begun to be very deficient, until towards the close of the 18th century, when the use of coke for fuel had been fully introduced and the improvement of the steam-engine had been effected, large importations of iron were rendered necessary for the consumption of the country.

Simultaneous with these importations, attempts were made by English capitalists to smelt iron by charcoal, at a less expense, by means of leasing the cuttings of natural woods in Devonshire and Wales, and sending the ores thither. Two establishments of this kind in Argyleshire, and one in the Island of Arran, on the west of Scotland, each with a single blast furnace, existed also from the middle till towards the end of the 18th century. One of these, called the Lorn works, near Inverary, survives all the others, being still conducted for the manufacture of charcoal iron,—and at the present time, in Great Britain, the use of wood charcoal for the purpose of smelting iron, is confined to Lorn works, and Newlands, and one or two other furnaces in the neighbourhood of Ulverstone in Lancashire.

The chief importations of iron were from Sweden and Russia, but the colonies in North America, from the commencement of the 18th century up to the war of separation, supplied an increasing proportion, the abundance of wood in those regions enabling them to smelt the ore at little expense. The iron manufacturers of Britain, alarmed for their own interests, when it was found that iron could be profitably produced in the British American colonies, and exported to England, made strenuous efforts, and obtained the insertion of a clause in an Act of Parliament in 1719, to prevent the manufacture of bar-iron, or of any kind of iron wares out of pig-iron, in any of the American plantations. About the year 1737 petitions were presented to parliament in favour of the importation of iron from America, but the iron-masters and proprietors of woods in Britain opposed, for the time, successfully, any legislative enactment being made for that purpose. Nevertheless, such was the feeling in favour of the measure, that, in 1750, an act was passed for encouraging the importation of pig-iron from British America. This act also permitted the importation of British American bar-iron into the port of London only. In 1756, an act was passed permitting the importation of bar-iron from the American colonies into all the ports of Great Britain, which liberty was extended to Ireland in 1765.

Scrivenor, in his 'History of the Iron Trade,' gives the exports of iron from the American Plantations from the year 1717, or soon after the commencement of the manufacture of iron in America, until the breaking out of the war of American Independence, in 1775, as under:

1717 and 1718 together, . . .	7 tons.
1729 to 1735 average, . . .	2,111 ,,
1739 to 1748 ,, ...	2,423 ,,
1750 to 1755 ,, . . .	3,305 ,,
1761 to 1776 ,, ...	4,045 ,,

By a memorial from the iron merchants in Scotland, to Oswald, under-secretary of state to the elder Pitt, against the restriction of the importation of iron from New England to the port of London, it appears that about 1750, nearly all the cast-iron then consumed in Scotland was received from the New England states.

The iron manufacture in Scotland is mainly carried on in Lanarkshire, and to some extent also in the counties of Stirling, Ayr, Linlithgow, and Fife.

The establishment, in 1760, of the Carron Works, on the small river of that name, in Stirlingshire, by Dr. Roebuck of Sheffield, in conjunction with other gentlemen, was a great attempt to manufacture iron by scientific processes, and that by means of a joint-stock capital guaranteed against indefinite liability by charter. Their capital stock was £150,000, divided into 600 shares. They employed at these works iron ore from Lancashire and Cumberland, along with ironstone from various places in the neighbourhood, limestone for fluxes from the Frith of Forth, and coal raised on the spot. In 1797, they had five blast furnaces in regular work, and their various operations gave employment to about 2,000 men,—and a large proportion of the pig-iron smelted at these works is still employed in the manufacture of every variety of cast goods.

In 1779, two brothers of the name of Wilson, merchants in London, established the Wilsonton iron works, in the upper portion of Lanarkshire, which, until the establishment of railways, were limited to two or three blast furnaces, on account of their distance from water carriage. The first operations in what is now the richest field of Scotland for the manufacture of iron, viz., that of the "black band," in which this mineral is found in combination with coal, were commenced in 1788, when the Clyde iron works were established in the neighbourhood of Glasgow. The peculiar qualities of the black band were not ascertained till about 1825. It was discovered and used as a mixture with other ores by Musket in 1801.

In 1788 there were only eight pig-iron furnaces in Scotland, of which four were at Carron, two at Wilsontown, one at Bunawe in Lorn, and one at Goatfield in Arran—the two latter being worked with wood-charcoal for fuel. In 1796 there were 17 furnaces. In 1830 there were 27; in

1846, 97; and in 1855 there were 113 furnaces in blast and 32 out of blast. The following table shows the increased average produce of each furnace since 1805:

Average Production of Each Furnace in Scotland.

In 1805.	25	tons weekly.
1825,	33 to 34	—
1843,	106 to 107	—
1844,	107	—
1845,	107 to 108	—
1846,	110	—

In 1827 the make of pig-iron in Scotland was only 36,500 tons; in the year 1854 it was about 800,000 tons.

The manufacture of malleable iron is of recent date in Scotland, as it can scarcely be said to have commenced till 1839, and no authentic note of the quantity made was kept till 1845, when it appears that the production was estimated at 35,000 tons, and the estimated production of malleable iron for the year 1854 was 125,000 tons.

The following particulars of the commencement of the present vast iron-works in the Merthyr district, in Glamorganshire, are from B. H. Malkin's 'Antiquities, &c. of South Wales,' who, writing in 1803, states that Merthyr Tydvil was a very inconsiderable village till about the year 1755, when an enterprising gentleman of the name of Bacon obtained a lease for 99 years, of a tract of minerals eight miles long and four wide, at a rent of £200 per annum. During the first 10 years of the lease little else was done in establishing works than the erection of one furnace, but subsequently the works were extended, a good road made to the port of Cardiff, and contracts for cannon, &c., executed for the government. About the year 1783, Bacon sublet portions of his minerals "in the following parcels: Cyfartha works, the largest portion, to Mr. Crawshay, for £5,000 per annum; Penderyn to Mr. Homfray, at £2,000 per annum; Dowlais Iron Works, to Messrs. Lewis and Tate; and a fourth part to Mr. Hill." The number of furnaces at Merthyr in 1803 was about 16, and there were also works at Aberdare and Hirwain.

In the year 1740 the quantity of charcoal pig iron made in England and Wales was 17,000 tons, in 1788 it was 13,000 tons, but in the latter year the pig iron made with the coke of fossil coal amounted to 48,000 tons, making a total of 61,000 tons. The improvement of the steam-engine by Watt, and the introduction of the process of puddling, for the conversion of cast iron into wrought iron, by Cort, in 1783, gave great impetus to the manufacture, and in the year 1796 the make of pig iron rose to 125,000 tons, and in 1830, including Scotland, to 678,000 tons. In the year 1829, James B. Neilson obtained his patent for the use of hot blast, the most important modern improvement in iron manufacture, causing both great economy of fuel, and increased production of iron in a given time, and in 1839 the make of pig iron in Great Britain was 1,248,000 tons, which increased to 1,999,000 tons in 1847, and to 2,700,000 tons in 1852.

The number of blast furnaces in Great Britain, and the production of pig iron in 1854 were as follows:—

	Furnaces.			Tons of Pig Iron.
	Built	In Blast.		
Northumberland, Durham, and Cleveland district,	78	59	produced	275,000
Yorkshire,	28	21	,,	73,444
Derbyshire,	33	25	,,	127,500
Cumberland and Lancashire,	5	3	,,	20,000
Staffordshire,	203	166	,,	847,600
Shropshire,	34	28	,,	124,800
Gloucestershire,	7	5	,,	21,990
North Wales,	11	9	,,	32,900
South Wales,	134	100	,,	750,000
do. Anthracite district,	35	21		
Scotland,	156	118	,,	796,604
Total,	724	555		3,069,838

Of this quantity, in round numbers, about one-half is exported. The declared value of the exports of iron, steel, &c., from the United Kingdom, for the year 1855, was as follows:

Iron and Steel,	£9,472,886
Hardware and Cutlery,	2,960,391
Machinery,	2,211,215
Tin Plates,	1,135,090
Coal,	2,439,432
	£18,219,014

The total declared value of all the exports from the United Kingdom, for the year 1855, being £95,669,380.

The iron of the West of Yorkshire is of very excellent quality, and furnishes some of the very best plates for steam boilers, as well as iron for other purposes. Shropshire also furnishes good boiler plate and bar iron, and some of the Shropshire foundry pig is very highly esteemed. Some of the Derbyshire works manufacture very superior iron. South Staffordshire produces largely sheet iron and good boiler plate, and some of the Staffordshire marks of sheet and bar iron have obtained a world-wide reputation. Wales is now the great seat of manufacture for railway iron and common descriptions of bar iron. Tin plates are also largely manufactured in South Wales. The iron of Scotland is well suited for common foundry purposes, and is largely exported to America, &c., in the form of pig iron. The iron of the new district of Cleveland, in the north-east of Yorkshire, is largely used for common foundry purposes, and also furnishes rails and common bars and plates. Some of this make of iron is used for the manufacture of common bars, &c., at works in other localities, as a mixture with other qualities of iron.

The irons which fetch the highest prices are the best of those manufactured at the works of West Yorkshire; then follow those of Shropshire, Derbyshire, and Staffordshire. The bar iron of Wales is mostly of a common description. The foundry iron of Scotland is produced at so cheap a rate as to have an influence on the iron market in all parts of the kingdom, and when low in price, finds its way into all parts even of the iron-making districts of England and Wales. The price of the Cleveland iron may be considered as being usually a little below that of Scotch pig of similar description.

The ancient iron works of Ireland were numerous and important, but they are now all extinct; and although of recent years several attempts have been made to resuscitate the manufacture, they have from some cause or other been wholly unsuccessful.

The following table shows the fluctuations in price of British iron during the last sixteen years:—

1825, Ordinary Bar Iron about £10 0 0 per ton.

	Welsh Rails at the Port.	Common Welsh Bar at the Port.	Scotch Pig Iron in the Clyde.	Scotch Bar Iron in the Clyde.	Staffordshire Bars at the Works.
1840,	——	£9 0 0	——	——	——
1841,	——	7 15 0	——	——	——
1842,	——	6 10 0 to £5 5	——	——	——
1843,	£6 10 0	4 15 0	——	——	——
1844,	6 15 0	5 10 0	——	——	£6 10 0
1845,	10 15 0	8 15 0	——	——	7 0 0 to £10
1846,	10 7 6	9 0 0	£3 10 0	£9 15 0	10 0 0
1847,	9 0 0	9 0 0	3 5 0	8 5 0	8 10 0
1848,	6 2 6	8 0 0 to £5 5	2 4 6	5 10 0	8 10 0 to £6 10
1849,	5 5 0	5 15 0	2 6 0	5 12 6	6 10 0 to £6
1850,	5 0 0	5 2 6	2 4 6	5 10 0	6 0 0
1851,	5 10 0	5 0 0	1 18 0 to £2 5	5 7 6	6 0 0
1852,	6 10 0	5 0 0 to £8	1 17 0 to £3 15	5 10 0 to £10	6 0 0 to £9
1853,	8 10 0	8 10 0	3 0 0	9 0 0	11 0 0 to £9
1854,	7 15 0	8 5 0	3 15 0	10 0 0	10 0 0 to £11
1855,	6 5 0 to £6 15	6 15 0	2 18 6	7 5 0	10 0 0 to £9
1856,	8 5 0	8 5 0	3 18 0	8 10 0	9 0 0

The prices of the various descriptions of British iron in the middle of the year 1856 were as follows:—

Rails in Wales,		£8	0	0	per ton.
Do. in Staffordshire,		8	10	0	,,
Bars in Wales,		8	0	0	,,
Do. in Staffordshire,		9	0	0	,,
Sheet Iron in Staffordshire,	£10 10 to	11	10	0	,,
Scotch Pig, No. 1, in the Clyde,	3 17 to	4	0	0	,,
Cleveland Pig, No. 1, in the Tees,		3	15	0	,,
Welsh Pig, No. 1,		4	0	0	,,
Do. Forge Pig,		3	10	0	,,
Staffordshire Forge Pig,		4	10	0	,,
Russian Bar Iron, CCND,		14	10	0	,,
Swedish Bar Iron,		14	15	0	,,

Although £9 per ton was nominally the price for Staffordshire bars in the autumn of 1856,—and though such price would be obtained by the leading houses making well-known marks of iron, in consequence of the slackness of trade, much underselling prevailed by less well-known or less wealthy manufacturers, to the extent of as much as even 30s. per ton below the nominal trade price; the British iron trade, in common with other industrial pursuits, being greatly affected by the depressing effects of heavy taxation, high price of provisions, and disturbance of commercial relations, induced by the calamitous war with Russia, which has happily just been concluded, and the prospect of any speedy improvement in this important branch of our national manufacture being but small—a reduction in price being by many considered as probable or inevitable.

Perhaps a more comprehensive statement, in a few words, of the comparative effects of peace and of war on the commercial prosperity of a nation, could not be readily met with than that of Robert Stephenson, M.P., F.R.S., in his address, as President, to the members of the Institution of Civil Engineers, early in the year 1856. After stating that the capital expended in making the then existing railways of Great Britain and Ireland was £286,000,000 sterling, he proceeds to observe:—"We have, indeed, already spent nearly a third of this sum, in two years, in the prosecution of the war in which this country is engaged; but it is impossible not to reflect, that if nearly £100,000,000 expended by the State, has only gained for us the advantage of occupying one side of the city, which the valour of England and of France has doomed to destruction, the expenditure of £286,000,000 by the people, has secured to us the advantages of internal communication, all but perfect,—of progress in science and arts, unexampled at any period of the history of the world,—of national progress almost unchecked,—and of prosperity and happiness, increased beyond all precedent."

DESCRIPTION OF THE MOST IMPORTANT SUBSTANCES CONCERNED IN THE MANUFACTURE OF IRON.

THE elementary, or as yet undecomposed substances, concerned in the manufacture of iron, with their "chemical equivalents," or proportions in which they combine with each other, by weight, are as follows:—

	Equivalent.
Iron,	28
Oxygen,	8
Hydrogen,	1
Nitrogen,	14·2
Carbon,	6·12
Silicium,	21·3
Aluminium,	13·69
Calcium,	20
Manganese,	27·7
Magnesium	12·7
Potassium (Kalium),	39·19
Sulphur,	16·1
Phosphorus,	15·7

For instance, one pound of hydrogen combines with eight pounds of oxygen, therefore the chemical equivalent of hydrogen is 1, and the chemical equivalent of oxygen is 8.

Compounds of metals with oxygen are termed oxides,—with carbon, carburets,—with sulphur, sulphurets. Compounds of sulphur with metallic oxides are called sulphates. When an acid the name of which terminates in *ic* unites with an oxide, the name of the resulting compound, or salt, is formed from that of the acid, but with the termination *ic* altered into *ate:* thus carbonic acid uniting with protoxide of iron produces carbonate of iron.

The following are the chemical equivalents of the principal compound bodies concerned in the manufacture of iron:—

	Equivalent.					
Protoxide of iron,	36,	composed of	1 equiv. oxygen	= 8,	and 1 equiv. iron	= 28.
Black oxide of iron,	116,	,,	4 equiv. oxygen	= 32,	and 3 equiv. iron	= 84.
Peroxide or Sesquioxide of iron,	80,	,,	3 equiv. oxygen	= 24,	and 2 equiv. iron	= 56.
Carbonate of iron,	58,	,,	1 equiv. carbonic acid	= 22,	and 1 equiv. protoxide of iron	= 36.
Silica,	45·3,	,,	1 equiv. silicium	= 21·3,	and 3 equiv. oxygen	= 24.
Alumina,	51·38,	,,	3 equiv. oxygen	= 24,	and 2 equiv. aluminium	= 27·38.
Lime,	28,	,,	1 equiv. calcium	= 20,	and 1 equiv. oxygen	= 8.
Carbonate of lime,	50,	,,	1 equiv. carbonic acid	= 22,	and 1 equiv. lime	= 28.
Magnesia,	20·7,	,,	1 equiv. magnesium	= 12·7,	and 1 equiv. oxygen	= 8.
Carbonate of magnesia,	42·7,	,,	1 equiv. magnesia	= 20·7,	and 1 equiv. carbonic acid	= 22.
Carbonic acid,	22.	,,	2 equiv. oxygen	= 16,	and 1 equiv. carbon	= 6.
Carbonic oxide,	14,	,,	1 equiv. oxygen	= 8,	and 1 equiv. carbon	= 6.
Cyanogen,	26,	,,	2 equiv. carbon,	= 12,	and 1 equiv. nitrogen	= 14.

IRON,

One of the most important and useful metals, may be said to be almost universally diffused, though of very rare occurrence except in an oxidized state. It constitutes great part of the colouring matter of rocks and soils; it is contained in plants, and forms an essential component of the blood of the animal body. Pure iron has a bluish gray colour; it is exceedingly soft and tough, and has a specific gravity of 7·78. Iron is strongly magnetic, but loses that remarkable property when heated to redness.—Redhot iron decomposes water, hydrogen being evolved, and the oxygen of the water uniting with the iron and forming black oxide.

Oxygen and iron have great affinity for each other; their three principal combinations being, protoxide of iron, consisting of 1 equivalent of oxygen and 1 equivalent of iron, and containing 77·80 per cent. of metal: black or magnetic oxide of iron, consisting of 1 equivalent of protoxide and 1 of peroxide, or 4 equivalents of oxygen and 3 equivalents of iron, and containing 72·4 per cent. of metal: and peroxide of iron, consisting of 3 equivalents of oxygen and 2 equivalents of iron, and containing 70 per cent. of metal.

The protoxide combines with carbonic acid and forms carbonate of iron, and carbonate of iron mixed with various proportions of earthy matter forms argillaceous iron ore. Spathose iron ore is crystallized carbonate of iron. On account of the facility with which the protoxide combines with oxygen, and passes into the form of peroxide or common red or yellow rust of iron, it is almost impossible to obtain it perfect, in a dry state. The red hematite of Lancashire, &c., is nearly pure peroxide of iron. Carbonate of iron consists of 1 equivalent of protoxide of iron and 1 equivalent of carbonic acid, or 62 per cent. of protoxide of iron, and 38 per cent. of carbonic acid, and contains 48·23 per cent. of metal: but the quantity of metal usually present in the impure carbonate or clay band ironstone of the coal measures is usually not more than 35 per cent., and frequently amounts to only 25 per cent. of the weight of ironstone. Argillaceous ironstone, of which three tons weight produce one ton of pig iron, may be considered as yielding exceedingly well.

Black oxide is formed when iron is heated in the open air, and the scales which fall from iron when it is rolled or forged hot consist principally of this oxide.

Black or magnetic oxide of iron is found in Sweden, in India, and some other localities. It is sometimes called oxydulous and octohedral iron, as crystallizing in octohedrons. It is also found massive and arenaceous.

Iron is infusible or nearly so, except when combined with a proportion of carbon, when it forms a fusible carburet of iron or "cast iron." Steel also is a carburet of iron. Malleable iron at a white heat becomes soft and pasty, and to this is owing the peculiar property that iron possesses of being welded or joined. The bar iron of commerce is not pure iron, but usually contains a small quantity of carbon, phosphorus, silicium, manganese, or sulphur, and cast iron usually contains the same foreign ingredients in a greater degree.

Schafhäutl calls attention to the circumstance that arsenic and phosphorus are but seldom absent in cast iron, bar iron and steel, a fact of which he has convinced himself by numerous analyses. He believes that the celebrated Dannemora iron and the capital Low Moor iron of England, owe their quality to the arsenic they contain, and that the excellent quality of the Russian CCND iron, (from Demidoff's iron works at Nischnetagilsk,) is owing to the presence of phosphorus.

Cast iron fuses at 2786° Fah.

The specific gravity of Malleable or Bar Iron is 7·664.

1 cubic inch of Malleable Iron weighs 0·2777 lbs.
1 cubic foot of Malleable Iron weighs 480 lbs.
1 foot length of Bar Iron, 1 inch square, weighs 3·333 lbs.
1 foot length of round Bar Iron, 1 inch diameter, weighs 2·61797 lbs.
1 square foot of Malleable Iron, 1 inch thick, weighs 40 lbs.
3·600 cubic inches of Malleable Iron weigh 1 lb. avoirdupois.

The specific gravity of good Cast Iron is 7·2648.

1 cubic inch of Cast Iron weighs 0·26330 lb.
1 cubic foot of Cast Iron weighs 455 lbs.
1 foot length of Cast Iron, 1 inch square, weighs 3·15971 lbs.
1 foot length of round Cast Iron, 1 inch diameter, weighs 2·48154 lbs.
1 square foot of Cast Iron, 1 inch thick, weighs 37·9166 lbs.
3·7978 cubic inches of Cast Iron weigh 1 lb. avoirdupois.

The weight of a piece of malleable iron of any given dimensions multiplied by 0·9479 gives the weight of a similar size of cast iron, and the weight of cast iron multiplied by 1·05495 gives the weight of a corresponding size in malleable iron.

Cast iron offers great resistance to a crushing force, but its tenacity is small. From 40 to 50 tons per square inch is the force necessary to crush cast iron, but in engineering constructions the safe amount of force acting in compression on cast iron should not be more than 6 tons per square inch. Malleable iron is crushed with a much less force than will crush cast iron, but malleable iron has a tenacity equal to from 20 to 30 tons per square inch, whereas the tenacity of average cast iron is only about 8 tons per square inch. Ordinary boiler-plate will bear about 23 tons tensile strain per square inch of section, but steam boilers made of such plate would burst at a pressure of 15 tons per square inch of section, as about one-third of the material will have been removed in punching the rivet-holes. The compression of wrought iron commences with a force of 10 or 12 tons to the square inch. The capability of wrought iron for resisting transverse strain is twice that of cast iron.

Five tons, per square inch of section, is the usual tensile strain to which wrought iron is subjected in construction, or 4½ tons, per square inch of section, of compressive strain; some engineers preferring to subject wrought iron to only 4 tons of compressive force per square inch.

The capability of a rectangular bar or beam of wrought iron to resist the effects of a transverse load or strain, when laid horizontally and supported at the ends, may be readily ascertained by the following formula:

$$w = \frac{b \quad d^2 \quad c}{l}$$

Where—

w = centre breaking weight, in tons.
b = breadth of beam, in inches.
d = depth of beam, in inches.
c = a constant, 28·6.
l = length of beam between supports, in inches.

For example.—Required to ascertain the weight that will break a rectangular bar of malleable iron, 3 inches in depth, $1\frac{1}{4}$ inch in breadth, and 8 feet between the supports, the bar being laid horizontally, and the weight applied at the centre of the span.

$$\frac{1{\cdot}25 \times 9 \times 28{\cdot}6}{96} = 3{\cdot}351 \text{ tons, centre breaking weight.}$$

If the weight be equally distributed over the whole span, the breaking weight will be double the above, or 6·702 tons.

If the bar be fixed at one end and loaded uniformly, one-half of the above is the breaking weight, or 1·675 ton.

If fixed at one end and loaded at the other, one-fourth of the above, or 0·837 ton, is the breaking weight.

The same formula will give the breaking weights of cast iron beams, by using as a constant 14·3 instead of 28·6, cast iron having only one-half the transverse strength of wrought iron.

In construction, the load that a beam will carry safely is variously estimated, by different engineers, at from one-sixth to one-third of the breaking weight.

The appearance of the fracture of either cast or wrought iron usually affords some criterion of its quality, but is not alone a safe and sufficient means of arriving at a correct conclusion.

The fracture of good fibrous wrought iron should be of a bright lead gray colour, with silky fibre, and no appearance of crystalline structure: it should be malleable, and bear hammering whether cold or hot; and if heated and suddenly cooled it should not become hardened or brittle. Some iron is malleable when hot, but exceedingly brittle when cold, and the reverse is the case with other descriptions, and such qualities of iron are respectively termed "cold short" and "red short." The method adopted in making the fracture will considerably influence its appearance: and in arriving at a judgment as to the quality of a sample of iron, it should be tried both hot and cold, and under a variety of circumstances; a favourite experiment with smiths in trying the quality of iron being to test its capability of forming a horse-shoe.

Cast iron of a dark colour and lustrous, is generally soft and tough, when of a light colour it is usually hard and brittle, but dark iron, showing but little metallic lustre, is generally weak and tender.

OXYGEN is a gas, and the most abundant element in nature, forming 8 tons in every 36 tons of air, 8 in every 9 of water, nearly a half of the more abundant earths, silica, and alumina, besides being found in almost all vegetable and animal matter.

Oxydating agents are substances which communicate oxygen with facility to other matters. The principal oxydizing agents are air, water, and acids and salts containing oxygen. Deoxydating agents are such as are powerful in removing oxygen, as carbon, hydrogen, and phosphorus.

Oxygen is the only gas that supports respiration, but it is not fit for breathing alone, as it destroys life after a few hours; and substances which do not undergo combustion in air burn, when previously ignited, with great brilliancy in oxygen gas: redhot iron, for instance, burns very readily.

One hundred cubic inches of oxygen gas weigh 34·4 grains.

The air which envelopes the globe is composed mainly of two gases—oxygen and nitrogen, and under ordinary circumstances consists, by weight, of—

Nitrogen,	75·88
Oxygen,	23·04
Watery Vapour,	1·03
Carbonic acid,	0·05
	100·00

One hundred cubic inches of pure and dry atmospheric air at 60° Fah., and 30 in. barometric pressure, weigh 31·01 grains.

The pressure of the atmosphere upon the surface of the earth is equal to 15 lbs. upon the square inch, thirty inches high of mercury, or a column of water 34 feet in height. Air expands by the application of heat at the rate of $\frac{1}{480}$ part of its volume for every degree of increased temperature.

There is always more or less of watery vapour in the atmosphere; the average proportion of water being about 1 to 1¼ per cent. of the whole weight. The colder and dryer air is, the denser and heavier it becomes; and this accounts for the well-known fact of fires burning quicker and brighter, chimneys acting better, and the ventilation of collieries being more active, during the prevalence of frost, especially if accompanied with north and north-easterly winds, than in warm and moist weather.

Hydrogen Gas is the lightest body in nature, 100 cubic inches weighing only 2·15 grains. It burns readily with oxygen, and evolves great heat. Hydrogen is a very powerful deoxydizing agent, and combines with a number of gaseous and other bodies forming compounds of great importance: with carbon it forms a variety of highly combustible and explosive gases, as light carburetted hydrogen (bihydruret of carbon), or fire-damp of collieries, olefiant gas, &c.

Water, or oxide of hydrogen, is a compound substance, consisting of 1 equivalent of hydrogen in combination with 8 equivalents of oxygen.

A cubic inch of water at 62° Fah. and 30 in. barometric pressure, weighs 252·45 grains, or ·03606 lb., being about 815 times heavier than air; a cubic foot of water weighs 62·5 lbs., and contains 6·25 imperial gallons; an imperial gallon weighs 70,000 grains, or 10 lbs. avoirdupois.

Water boils and is converted into steam under ordinary atmospheric pressure at the temperature of 212° Fah.; the greatest density of water is at 40·5, and it freezes at 32° Fah.

NITROGEN GAS is a most important constituent of the air as serving to moderate the action of oxygen during combustion, and the too great excitement which that gas respired unmixed would produce on the animal system.

Pure nitrogen or azote is fatal to animal life, and it extinguishes flame. With oxygen, in various proportions, it forms nitrous and nitric acid, nitrous oxide, &c.,—with hydrogen it constitutes ammonia,—with phosphorus it forms a phosphuret,—and with carbon, cyanogen. It also enters into the composition of most animal matter except fat and bone, and forms a part of most of the vegetable alkalies.

CARBON, an elementary body, is an infusible but combustible solid. It forms the principal part of coal and also of all animal and vegetable substances. Its most important compounds are those which it forms with oxygen, hydrogen, and nitrogen. In this place we need only notice carbonic oxide gas, which consists of 1 equivalent of carbon and 1 equivalent of oxygen, and carbonic acid gas, which is formed of 1 equivalent of carbon and 2 equivalents of oxygen.

Carbonic acid, the choke-damp of collieries, is produced by the combustion of carbon, by fermentation, putrefaction, and in the process of respiration. It is fatal to animal life, being a powerful narcotic poison, and it extinguishes flame. Carbonic acid is a heavy gas, one hundred cubic inches weighing 47·3 grains, therefore its density is to that of atmospheric air as 1·526 to 1. Carbonic acid forms nearly 44 parts in every 100 parts of limestone and marble; besides occurring united with various earths and metallic oxides, in solution in most spring water, and to a small extent in the atmosphere.

Carbonic oxide is formed by carbonic acid, the result of combustion, passing over ignited fuel, and dissolving or combining with a portion of carbon, the result being the formation of inflammable carbonic oxide gas, of twice the volume of the uninflammable carbonic acid gas. Carbonic oxide is a powerful agent in the reduction or deoxydizing of metallic oxides; it is the principal reducing gas in blast furnace operations, and it also forms the major portion of the gases given off at the tunnel head. Carbonic oxide is fatal to animals, and extinguishes a taper immersed in it, but when it meets with oxygen it burns with a blue flame, and is converted into carbonic acid; with a proportion of atmospheric air it forms a highly explosive compound.

One hundred cubic inches weigh 30·1 grains.

Karsten states that he found as much as 5·5 per cent. of carbon in foundry pig iron, and that iron containing as little as 2·3 per cent. of carbon still retains the properties of cast iron. With 2 per cent. of carbon iron is not forgeable, and scarcely so if it contain 1·9 per cent.: with this quantity of carbon it is steel. Even with so small a proportion of carbon as 1·75 per cent. it is weldable only in a slight degree. An amount of from 1·4 to 1·5 per cent. of carbon in iron denotes the maximum of both hardness and strength. Iron containing 0·5 per cent. of carbon is a very soft steel, and forms the boundary between steel (*i. e.* iron which may be hardened) and malleable or bar iron.

SILICIUM, or silicon, an elementary body, may be procured in the form of a dark brown powder. Silicium in combination with oxygen forms silica, silex, or silicic acid, which, next to oxygen, is one of the most abundant substances in nature, entering largely into the composition of minerals, rocks, sands, &c. Colourless rock crystal is pure silica, and common quartz and flint are mainly composed of silica. Silica is a very fine white tasteless powder, and is infusible except by means of the flame of the oxyhydrogen blow-pipe. It is a powerful acid, though its insolubility in water prevents its manifestation of acid properties under ordinary circumstances. Although infusible alone, it combines at a high temperature with the alkaline earths, lime, magnesia, &c., as an acid with a base, forming silicates of lime, &c. The compounds of silica or silicic acid, with excess of alkali, are caustic and soluble, but those with an excess of silica are insoluble, and form glass; with alumina it forms the less fusible compounds of porcelain and stone ware.

ALUMINIUM, a metal of a tin-white colour, and perfect lustre. It is malleable, and requires for its fusion a temperature higher than that at which cast iron melts. The combination of oxygen with aluminium forms alumina. Alumina is a white, tasteless, friable substance, fusible by means of the oxyhydrogen blow-pipe. The mineral corundum is pure alumina, as also are the sapphire and ruby, with the exception of the colouring matter. Alumina enters largely into the formation of various rocks and minerals; the varieties of clay are essentially silicates of alumina, but vary in composition. China clay is the result of the decomposition of the felspar and mica of granite: Stourbridge fire-clay consists of 1 equivalent of alumina in combination with 3 equivalents of silica.

CALCIUM is a silver-white metal, having a very great affinity for oxygen, the resulting compound or oxide of calcium being lime. Carbonate of lime, or lime in combination with carbonic acid, forms rocky beds of immense extent and thickness in most parts of the world. Limestone, chalk, and marble consist of carbonate of lime, with more or less of other ingredients, as magnesia, clay, and ferruginous and bituminous matters. Calcareous spar and statuary marble are nearly pure carbonate of lime, or 44 parts of carbonic acid and 56 of lime. Lime is prepared by exposing limestone or chalk, &c., mixed with coal, to a strong heat, by which means the carbonic acid is expelled, and quicklime produced. Lime, though infusible alone, promotes the fusion of all the other earths, and serves as a flux for alumina and silica.

MANGANESE is a greyish white metal. It is hard and brittle, and extremely difficult of fusion; it oxydizes so rapidly that it is necessary to keep it in a stoppered bottle under naphtha. It decomposes water rapidly at a red heat. As a metal, manganese has seldom, if ever, been obtained chemically pure, the best specimens containing carbon, and being more properly carburet of manganese than the pure metal. The most common ore is the peroxide, consisting of 1 equivalent of manganese combined with 2 equivalents of oxygen. It is found in Devonshire, Somersetshire, and Aberdeenshire, in both a massive and crystallized form; and it is largely used in science and the arts as a source of oxygen.

MAGNESIUM is a white malleable metal, fusible at a red heat. Heated in the air it burns and forms magnesia, which is the only oxide. Magnesia, one of the alkaline earths, is almost infusible, and a mixture of lime and magnesia is scarcely more fusible than the earths separately.—Carbonate of magnesia occurs in combination with carbonate of lime, and most of the calcareous rocks contain a small quantity of magnesia. Magnesian limestone consists of 1 equivalent of carbonate of lime associated with 1 equivalent of carbonate of magnesia.

POTASSIUM is a brilliant white metal with high lustre, and possessing extraordinary properties. It is lighter than water, and floats upon it, and it melts completely at 150°.—It oxydizes rapidly upon exposure to the atmosphere, (having a stronger affinity for oxygen than any other known substance), forming potash or potassa, which is composed of 1 equivalent of potassium and 1 equivalent of oxygen. Hydrate of potash or caustic potash consists of 1 equivalent of potash and 1 of water.

SULPHUR, an elementary body of great importance and interest. It is often found in a free state and also in combination with oxygen and metals, as in iron, copper, and other ores. It is a pale yellow brittle solid; it melts and becomes quite fluid at 226° Fah., between 430° and 480° it becomes thick and tenacious, and between 480° and its boiling point, 600°, it again becomes thin and liquid. Iron, at a white heat, readily combines with sulphur, forming sulphuret of iron, which is composed of 28 parts of iron and 16 of sulphur. There are eight compounds of sulphur and oxygen; sulphurous acid, consisting, by weight, of 16·09 sulphur and 16 of oxygen, is the product of the combustion of sulphur in dry air or oxygen gas; it is also found in the air in the neighbourhood of copper and other works, and in large cities: it is a colourless gas, and 100 cubic inches weigh 68·69 grains. Sulphurous acid gas is quite irrespirable and extinguishes flame, and is equally inimical to animal life and to vegetation.

PHOSPHORUS has a pale yellow colour, and the consistency and appearance of wax, and inflames with great facility. There are five combinations of oxygen and phosphorus, the most important being phosphoric acid, which is produced by the vivid combustion of phosphorus. Phosphorus is found in the animal, vegetable, and mineral kingdoms, chiefly in the form of phosphoric acid united with various bases. The earthy phosphates play a very important part in the structure of the animal frame, by communicating stiffness and inflexibility to the bones. When bones are calcined with access of air, the residuum, after the organic portions are destroyed, consists of a mixture of superphosphate of lime and carbonate of lime, affording 12 or 14 per cent. of phosphorus. Most, if not all, of the fossiliferous iron ores, contain phosphoric acid, which has the effect of increasing the fluidity of fused cast iron; the addition to the burden of a furnace of a considerable proportion of iron ore, containing phosphoric acid, has a very perceptible effect in increasing the fluidity of the pig iron whilst in a state of fusion.

CYANOGEN is a pungent suffocating gas, very inflammable, and burns with a beautiful purple-coloured flame,—but a taper immersed in it is extinguished. Cyanogen does not exist in nature ready formed, but is produced abundantly by bringing its elements together at a high temperature in contact with substances with which it may unite, and compounds of cyanogen are evolved during the distillation of coal in the manufacture of gas. Prussian blue is a chemical compound of cyanogen and iron, and prussic or hydrocyanic acid is composed of 1 equivalent of cyanogen and 1 equivalent of hydrogen. The specific gravity of cyanogen is 1·815. When potassium is heated in cyanogen gas it takes fire and burns, yielding cyanide of potassium. Cyanide of potassium forms colourless cubical crystals, very soluble in water, it is a violent poison, and at high temperatures is a very powerful reducing or deoxidizing agent. Cyanogen is one of the gases produced in blast furnace operations; and cyanide of potassium is also formed where the materials contain potash. The late Professor Fownes, in his 'Manual of Chemistry,' states, that if nitrogen gas be passed through a white hot tube, containing a mixture of carbonate of potash and charcoal, a considerable quantity of cyanide of potassium will be formed—carbonic oxide being at the same time extricated.

DESCRIPTION OF THE VARIETIES OF IRON ORE USED IN GREAT BRITAIN—THEIR GEOLOGICAL DISTRIBUTION, &c.

The chief source of a supply of ironstone for the British Iron Manufacture is the coal measures, from which is obtained the argillaceous or clay band ironstone, being a carbonate of the protoxide of iron in combination with silica and alumina, with occasionally a proportion of lime, magnesia, sulphur, phosphorus, or other substances. Black band is a variety of this description of ironstone, having, in addition to silica, &c., a considerable quantity of carbonaceous matter in its composition, to which is owing the colour which gives it its characteristic name—some of the best specimens consist of little else than carbonate of iron, and carbonaceous and bituminous matter.

The compact carbonate or clay band ironstone of the coal measures may be considered as usually consisting of from 50 to 75 per cent. of carbonate of iron, with from 25 to 50 per cent. of earthy matter,—as silica, alumina, lime, &c.,—and containing from 24 to 36 per cent. of iron.

Black band ironstone commonly consists of from 40 to 75 per cent. of carbonate of iron, with 10 to 25 per cent. of carbonaceous matter, and from 15 to 35 per cent. of silica, &c., and containing from 19 to 35 per cent. of iron.

The compact carbonates have all a stony texture and appearance, but vary much in colour,—their usual specific gravity being from 3·10 to 3·40, and producing on an average about 30 per cent. of pig iron.

Black band has not so high a specific gravity as the clay band stone, nor does it usually produce so large a per centage of metallic iron, but it is a very valuable material to the iron manufacturer, as it is usually found in much thicker deposits or layers than the clay band stone, and is consequently cheaply worked,—and the quantity of carbonaceous matter combined with it renders it capable of being calcined with very little or no additional fuel,—and it is even, in some cases, worked in the blast furnace without undergoing any torrefaction.

Argillaceous ironstone is found to a greater or less extent in all the coal deposits. The black band ironstone is most extensively employed at the Scotch iron works. It is also found, and more or less extensively worked, in numerous places in the South Wales coal field,—also in North Wales, Northumberland, Durham, Staffordshire, &c. The thickness of the beds of black band ironstone varies from a few inches up to 3, 4, or more feet in thickness. Argillaceous iron stone is generally found in pretty regular deposits, which often hold through considerable ranges of strata; but the deposits of black band ironstone are very uncertain and irregular, frequently passing, even within a very short distance, into carbonaceous shale, or even coal.

The argillaceous ironstone of the coal measures is usually found in beds, in detached pieces or nodules of irregular form, but generally somewhat flattened in a direction parallel with the plane of deposition of the surrounding strata.

The thickness of the deposits varies from a single course, band, or pin, of from 1 inch or 1½ inch to 4 or 5 inches in thickness—to perhaps six, eight, or more courses, each of an inch and upwards in thickness, imbedded with more or less regularity, in from 3 or 4 up to perhaps 20 feet thickness of shale, bind, &c.,—much of the value of the deposit depending upon a sufficient number of courses being so near to each other as to be worked without the necessity of removing a great thickness of ground.

The colours of the coal measure ironstones are brown, black, blue, light and dark drab, and various shades of brownish and yellowish-grey. The texture is commonly very compact, and the fracture rough and uneven.

Next to the coal measures, the mountain, carboniferous, or transition limestone, which underlies the millstone grit, is the formation from which the most valuable supplies of iron ore are procured; amongst which are the 'hematite,' or red ore of Lancashire and Cumberland, which is nearly pure peroxide of iron, and is largely worked in the Whitehaven, Ulverstone, and Furness districts, for exportation to the North and South Wales, South Staffordshire, Yorkshire, and other iron-making districts. It is found in beds varying from a few feet to upwards of ten yards in thickness; and also in veins, or rather pockets or chambers.

The hematite or red ore is found both compact and friable —the former being used for the blast furnace, and the latter for lining the sides and bottom of puddling furnaces.

The colour varies from a bright to a dark red—some specimens showing considerable metallic lustre, others being dull and earthy-looking and having an unctuous feeling when handled. Other specimens show a compact fibrous fracture. Very variable as regards hardness.

The varieties of iron ore called 'brown hematites,' which are found and largely worked in the Forest of Dean, Gloucestershire, at Alston Moor, Weardale, &c., in the counties of Northumberland and Durham, in the Cardiff Valley, and other places on the south-east crop of the South Wales coal field, and which are also found in Derbyshire and Somersetshire, are from the mountain limestone.

'Brown hematite,' or hydrated peroxide of iron, appears to be the result of decomposition of varieties of carbonate of iron by atmospheric or other influences.

Red and brown hematite are found in the county of Cornwall, in the clay slate or killas which commonly reposes on the granite. Hematite, hydrous peroxide, sparry carbonate, and brown iron ore, are all found at Restormel, near Lostwithiel. Magnetic oxide and micaceous iron ore are found in the granite in Devonshire. A crystallized brown iron ore is procured from Silurian limestone at Brixham, near Tor Bay. Hematite is found in the Devonian formation of West Somerset, in the Brendon Hills. Hematitic conglomerate is found at Brockwell, near Wootton Courtney, and Minehead; in West Somerset, and at Newent and other places in Gloucestershire, in which localities the new red sandstone is in immediate juxtaposition with the old red Devonian, or Upper Silurian; white carbonate, or spathose, foliated, or sparry iron ore, is also found in West Somerset. The clay slate, lower killas, or lower Silurian, in North Wales, contains deposits of iron ore which have been worked to some extent at Tremadoc, Pwllheli, &c.

The white carbonates, and red and brown hematites of Exmoor Forest, Devonshire, are now about being extensively worked by parties engaged in the iron manufacture in South Wales and other localities, some of whom have leased large tracts of these rich deposits.

The inferior oolite affords large quantities of ironstone, which is worked to a considerable extent in various places in the county of Northampton, for exportation to the South Staffordshire and Derbyshire coal fields. The Northamptonshire ironstone can be raised very cheaply owing to the thickness of the beds, which are in some places several feet thick. The raw stone is about 3s. 6d. per ton, long weight, in Northamptonshire, or 6s. 6d. delivered in Staffordshire; the calcined ore is 13s. per ton, delivered in Staffordshire. The ore varies much in quality, and generally is not in very high favour: from its tender and friable character, in raising and removing a large proportion of it is reduced to small fragments, which renders it less favourable for the blast furnace than if it were more compact. Ironstone, in the inferior oolite, is also worked at Whitby. The ironstone of the lias of the Cleveland district, in the north-east of Yorkshire, is very extensively worked in the neighbourhood of Middlesborough, Guisborough, Hutton, Eston, &c. These deposits of ironstone were discovered about five years ago, and during that time upwards of 30 new blast-furnaces have been erected in the neighbourhood of Middlesborough for working the Cleveland ironstone; and it is also exported largely for the use of the iron works on the Tyne, and other places in the counties of Northumberland and Durham. The fuel used at the iron furnaces of the Cleveland district is coke from the South Durham coal field. The Cleveland ironstone is found in beds, very compact, and several feet in thickness, and the cost at the blast furnaces is about 4s. per ton. The ore has a stony appearance, and is of a pale brown or greenish-grey colour.

The following is the analysis of Cleveland iron ore, by A. Dick, of the School of Mines:—

Protoxide of Iron,	39·92
Peroxide of Iron,	3·60
Protoxide of Manganese,	0·95
Alumina,	7·86
Lime,	7·44
Magnesia,	3·82
Potash,	0·27
Carbonic Acid,	22·85
Phosphoric Acid,	1·86
Silica, soluble in hydrochloric acid,	7·12
Bisulphide of Iron, (iron pyrites),	0·11
Sulphuric Acid,	a trace.
Water in Combination,	2·97
Residue, insoluble in hydrochloric acid,	1·64
	100·41.

Containing 33·57 per cent. of Metallic Iron.

"The silica which existed in the hydrochloric acid solution was that which was present in a state of combination in the ore, probably with both protoxide and peroxide of iron; and the peculiar greenish-grey colour of the ore was doubtless due to the presence of this silicate of the mixed oxides of iron, just as the colour of the green particles in the so-called green sand is believed to be due to the like cause.

"The proportion of phosphoric acid in the ore is comparatively large, and may be easily accounted for by the fossiliferous character of the ore. The quality of the iron smelted from this ore would certainly be very sensibly affected by the proportion of phosphorus, and probably also by the silica existing in a state of combination."—*Phil. Mag.* S. 4. Vol. XI. No. 74.

The argillaceous ironstone of the lower green sand, and of the Hastings sands, and other strata of the Wealden fresh-water formation, were, when wood charcoal was the fuel employed in the smelting of iron, extensively worked in the counties of Sussex, Surrey, and Kent, being the source of supply of ironstone for the works of that once noted iron-making district.

SMELTING.

The method formerly everywhere adopted for obtaining iron from the ore, and which method is still in use in some parts of the Continent of Europe, in America, India, &c., was to break the ore into small pieces, and heat it in contact with wood charcoal,—the fire being urged with bellows worked by hand or water power,—until the iron was deoxidized or reduced into a metallic state, and softened into a pasty mass; it was then taken out of the fire, and being placed under a hammer, the cinder or earthy matter was forced out, and the iron to some degree condensed. It was then again heated and hammered until the desired form was obtained.

A small quantity only of material can be operated upon by this method, and it is necessary not only that the iron ore should be rich and comparatively pure, but a large quantity of wood charcoal is required in the process, and even under these conditions a large amount of metal is wasted, and the labour is great in proportion to the quantity of iron procured.

In the 16th century wood for charcoal began to get scarce in the iron-making districts of Britain, and our ancestors were obliged to procure a large portion of their supply of iron from countries in which, in addition to rich deposits of iron ore, there was abundance of wood for charcoal, as Sweden and Russia.

The successful attempt to use coke or charred coal in the place of wood charcoal, although its introduction had for a long period to contend with a vast amount of prejudice and opposition, gave a fresh impetus to the iron manufacture in

Britain, though large supplies of iron continued to be imported from Russia and Sweden after the use of fossil coal was introduced. But although, in more recent times, considerable improvements had been made in this kingdom in the iron manufacture, amongst the principal of which may be mentioned Cort's process of puddling, for converting pig or cast iron into wrought or bar iron, still it was the introduction of the use of hot blast, or blowing heated air into the furnace instead of cold air, coupled with the possession of immense supplies of excellent coal, that has given Britain her present important superiority over all other iron-producing countries.

The process adopted at the present time in Great Britain for manufacturing iron from the ore, consists of two parts;—the first part being the production of cast iron, and the second part consisting in the conversion of the cast iron into bar or wrought iron.

The manufacture of cast iron consists of placing the ore, fuel, and necessary flux, mingled together, in a furnace of considerable height, and exciting vivid combustion by means of an abundant supply of air—and as the furnace is quite closed up at the bottom the necessary supply of air has to be forced in by means of a steam engine or other power, and from this circumstance it is called a "blast furnace." The ore is in the form of oxide of iron, and the carbonic oxide and hydrogen formed during the process of combustion remove the oxygen from the ore, which becomes carburetted, or saturated with carbon, and the iron falls into the bottom or hearth of the furnace in the state of carburet of iron—the cast or pig iron of commerce. The earthy matters combined with the ore, after being melted in conjunction with the flux with which they unite to form a fusible slag or cinder, are allowed to escape in a fluid state from the lower part of the furnace,—and the pig iron is tapped or run out from the furnace hearth as soon as a suitable quantity has collected.

The subject of the conversion of cast iron into soft, malleable, or wrought iron, will be considered in a subsequent section.

Fig. 1. ELEVATION.

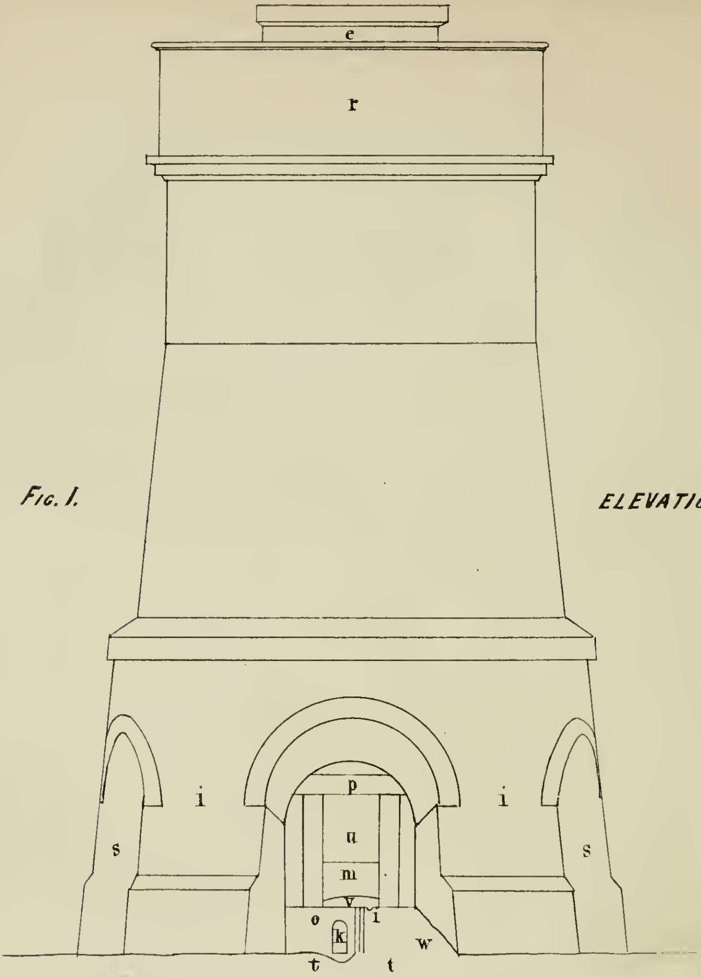
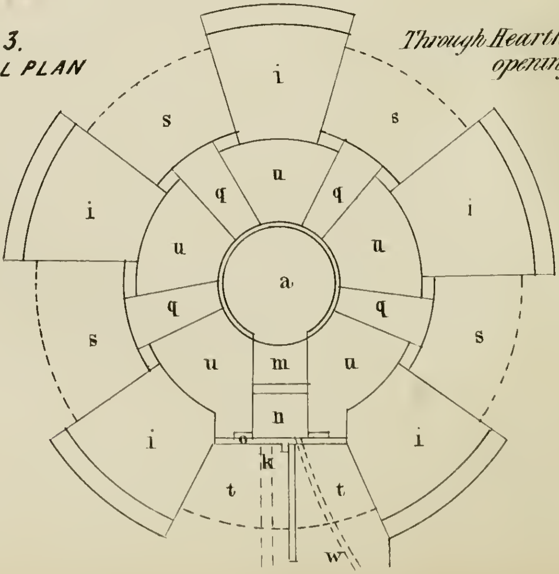


Fig. 3. SECTIONAL PLAN

Through Hearth & Tuyere openings



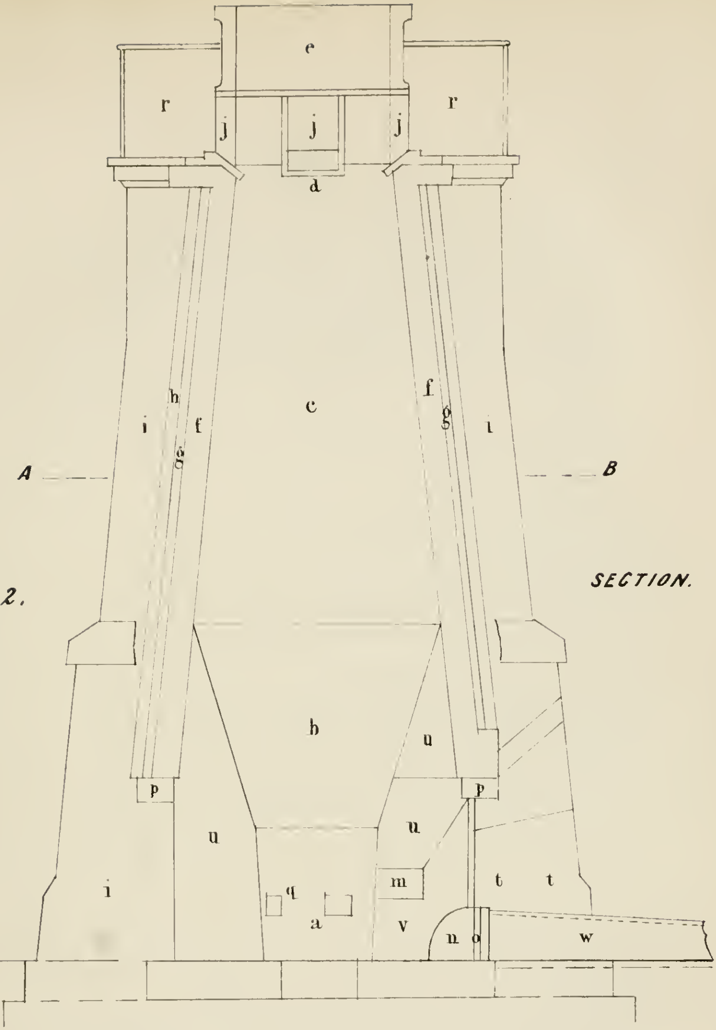


FIG. 2.

SECTION.

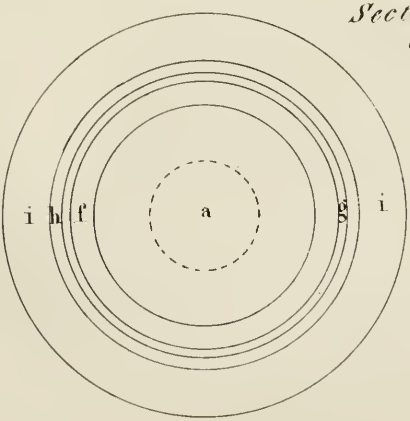


FIG. 4.

Sectional Plan at A B.

The furnace in which the process of smelting is thus conducted is called the blast furnace. The exact form and proportions are not of importance, and at nearly every ironwork some difference in these respects prevails. One of the most usual modern forms is given in the accompanying sketches, Fig. 1, 2, 3, and 4, which are drawn to a scale of ten feet to an inch.

A blast furnace may be considered to consist essentially of three parts,—the hearth in which the iron produced is collected, and in which part also the blast for exciting combustion is introduced; the boshes which serve to guide and facilitate the regular descent of the materials to the hearth; and the body or upper part of the stack which contains the bulk of the material in different stages of progress towards reduction to iron or slag.

Fig. 1 is the external elevation of a blast furnace, circular in plan. Fig. 2 is a vertical section of Fig. 1, through the tymp and centre of furnace. Fig. 3 is a sectional plan through the hearth, showing the tuyere-holes; and Fig. 4 is a sectional plan of body of furnace, on the line *A B* in Fig. 2. The same reference-letters apply to the same parts in the four sketches.

a. hearth.
b. boshes.
c. body of furnace.
d. throat.
e. tunnel-head.
f. fire-brick lining, from 12 to 15 inches in thickness.
g. sand backing, about 4 inches in thickness.
h. fire-brick of about 6 inches in thickness; the object of this additional fire-brick is to prevent the external brickwork or masonry being damaged or destroyed in the event of any part of the inner lining being burned through.
i. external brickwork or masonry, which must be so constructed as to allow of the whole of the hearth, the boshes, the inner lining, and sand backing being removed for the purpose of repairs without disturbing the external work. The exterior brick-work is usually strongly hooped with iron.
j. openings (of which there are usually four) in the tunnel-head, at which the materials are introduced into the stack.
k. tapping hole in the dam-stone, at which the iron is run from the hearth.
l. cinder notch, in the dam-stone, from which the slag flows.

m. the tymp, which partially closes the opening in the "fore-part," and which is renewed occasionally when burned away.
n. the dam-stone, which, as the name implies, closes the outlet from the hearth and dams back the iron and cinder.
o. a strong iron plate for increasing the strength and security of the dam-stone, and termed the dam-plate.
p. iron-bearers for carrying the lining over the openings in the lower part of the stack.
q. the tuyere-holes, in which the "tuyeres" or pipes through which the blast is discharged into the hearth, are placed.
r. plate-iron screen round tunnel-head.
s. the tuyere-houses.
t. fore-part or front of furnace.
u. walls of hearth, sometimes constructed of refractory sandstone, but more usually of fire-brick.
v. opening from hearth to dam-stone and tapping-hole.
w. the fald, a heap of ashes, over which the cinder is led in a small channel as it flows from the cinder-notch.

A furnace of the above dimensions worked with coke in a judicious manner, and with argillaceous stone of average quality, would produce about 120 tons of No. 4 grey forge pig weekly.

Fig. 5.

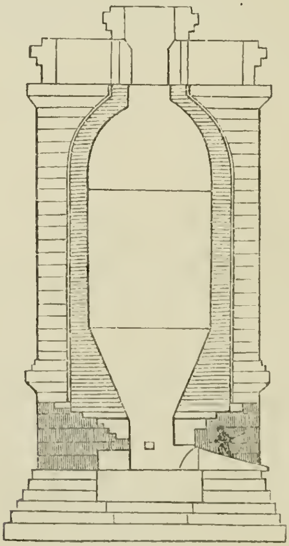


Fig. 5 is a vertical section of a blast furnace of a different construction to Fig. 1. The base is square, as also is the hearth; the tuyeres being placed one on each side, and one at the back of the furnace. The section is made in the plane of one tuyere, and through the tymp, at right angles to the other two tuyeres. The interior is cylindrical, from the top of the boshes to within a few feet of the filling places, where it is rapidly contracted to the desired width for the throat of the stack. The exterior of the furnace is also cylindrical above the string-course moulding of the base.

Applying a scale of 20 feet to the inch to this sketch, will give the dimensions of a moderate-sized furnace; a scale of 25 feet to the inch will give a large furnace. It would be preferable, especially if the furnace were at all a large one, to use five tuyeres instead of three only, viz.: two, at a small distance from each other, on each side, and one at the back, or even two at the back also.

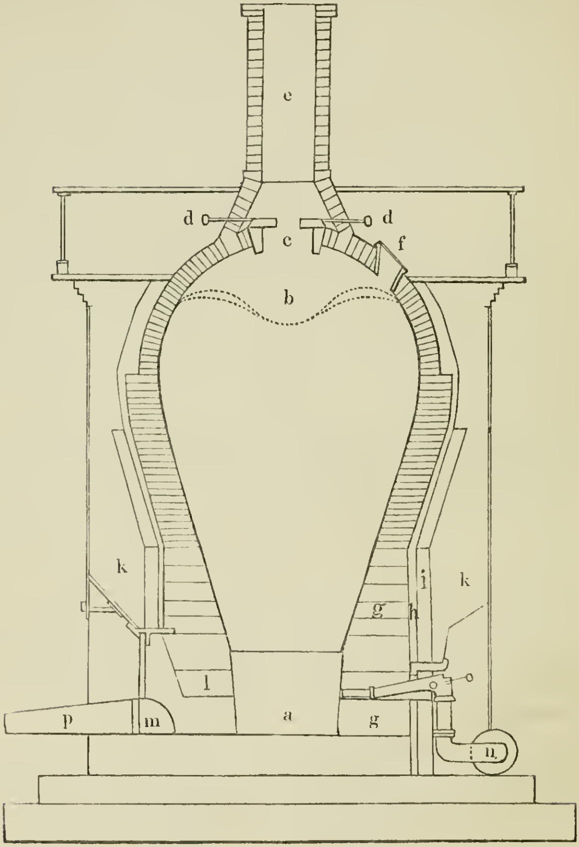
Furnaces constructed according to Fig. 5 have given very satisfactory results, but Fig. 1 is the form most usually adopted.

Departures to a greater or less extent from the more usual forms of blast furnaces are made occasionally, and with varying success. Perhaps one of the greatest variations that has been tried of recent years, is that shown in Figs. 6 and 7.

Fig. 6 is a vertical section of a blast furnace through the tymp to centre of furnace, and through the tuyere-hole, marked s on the plan; the scale being ten feet to the inch.

a. the hearth.
b. the dome.
c. the throat, which may be contracted by the sliders d, of which there are six.
e. the chimney.
f. filling place, of which there are six, and which are closed except when introducing materials.
g. sand-stone hearth and boshes,—the body of the furnace and dome being fire-brick.
h. sand backing.
i. fire-brick.
k. external brickwork.

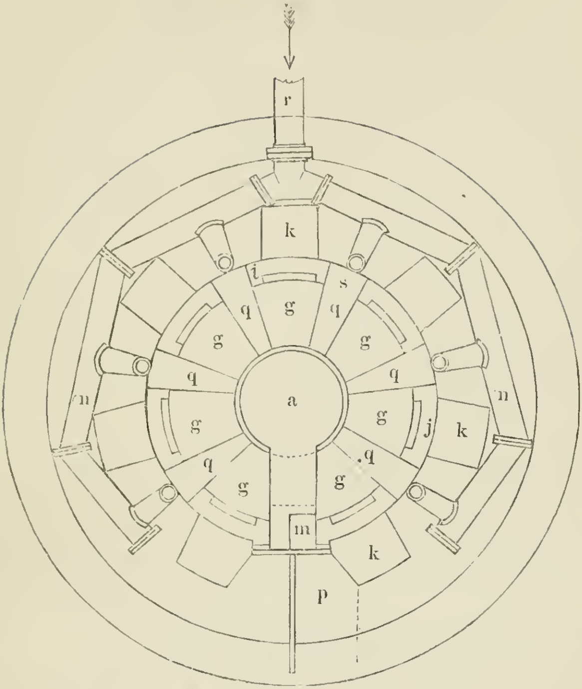
Fig. 6.



l. tymp.
m. dam-stone.
n. pipes for conveying blast.
o. tuyere and nozzle.
p. the fald.
q. the tuyere-holes.
r. main blast-pipe from engine.
s. tuyere-hole, through which section Fig. 6 is taken.

Fig. 7 is plan of above furnace at the tuyeres, of which there are six.

FIG. 7.



A patent was secured for this furnace, and one or two furnaces erected; but they were not found to answer, and were re-constructed,—the principles upon which the furnace was designed being unsound. The dome is intended to increase the heat in the upper part of the furnace, by causing the flame to reverberate upon the materials,—this caused the furnace to work too hot at the top, and melted the materials into slag. The narrow throat and chimney were intended to assist the draught of air through the furnace; and the closed filling-places assisted in preventing the escape of heat. The main object appears to have been to obtain a high temperature with the smallest expenditure of fuel, and if this were the only point requiring attention in the smelting of iron, it would no doubt have been secured to a great extent by the construction adopted; but the furnace worked so hot and irregularly, that its operation was shortly discontinued.

The external form of blast furnaces varies greatly in different localities, and is not of much importance so long as the work is solidly built, and facilities are provided for the escape of any dampness; or if the work is of a slighter character, it should be well secured with wrought iron hoops or ties. Where abundance of stone exists the furnaces are usually built of a square pyramidal form—the fore-part being in one side, and a tuyere-house in each of the other three sides.

The dimensions of furnaces vary much; but a furnace of from 12 to 13 feet in diameter at the widest part of the boshes, and from 40 to 45 feet in height to the filling-place, may be considered sufficiently large, especially if a good quality of iron is desired. Some furnaces are constructed 15 feet in diameter at the boshes, and 50 feet and upwards in height, and some few even as much as 18 feet in diameter at the boshes. Large furnaces are frequently unmanageable, and when anything untoward occurs in their working, it is more serious and difficult to restore a proper state of things than with a smaller furnace.

As all the raw material is required at the tunnel-head, in hilly districts the furnaces are usually placed at the foot of a slope or bank, so as to bring the filling-places at or about such a level as to allow of the materials being run in wagons or trams, over a bridge or platform, to the tunnel-head, thus preventing the necessity of hoisting the materials to the top of the furnace. This arrangement is frequently carried out, but care should be taken that the furnaces are not placed in a damp situation; and in all cases the foundations of furnaces should be constructed so as to entirely prevent any dampness rising to the hearth.

In localities in which the materials have to be hoisted to the top of the furnace, an incline is sometimes used, the materials being drawn up either by the blowing-engine or a separate engine for the purpose. Sometimes a perpendicular hoist, worked by compressed air from the blast-engine, is employed,—in other cases the water-balance is used, the water being forced to the required height by a pump worked by the blast-engine.

The ironstone when first raised has more or less of shale, &c., adhering to it, therefore it is usual to expose it to the action of the weather for a longer or shorter time, by which means the shale is detached. The ironstone is then calcined, i. e., it is subjected to a red heat, either in kilns or in heaps upon the ground, small coal and coke being mixed with it. By this process the carbonic acid, moisture, and a part of the sulphur, &c., are driven off, and the protoxide of iron in combination with the carbonic acid is not only changed into the state of peroxide, but another very important effect is produced — the ironstone is rendered porous, by which means the interior portion of the ironstone is more fully exposed, when in the blast furnace, to the effect of the reducing gases, and is alike deoxidized as the exterior portion. If very compact ores were used without being previously rendered porous through the carbonic acid, &c., being driven off by calcination, the outside portion of the ironstone would become deoxidized, but the interior portion would not be affected. It is desirable therefore, in calcining ironstone, that it should be exposed to a heat sufficient to expel the carbonic acid, water, sulphur, &c., without raising the heat to such a degree as to cause the ironstone to run and clinker together in masses, as sometimes happens.

It is usual to designate ironstone, after it has been calcined, by the name of "mine;" and in some districts it is always so called even before roasting.

By the process of calcining, argillaceous ironstone loses from 25 to 30 per cent. of its weight, and, as an average, about 10 cwts. of coal will be consumed in calcining 3 tons of clay band ironstone.

In some localities calcining is nearly all done in kilns, in other places entirely in heaps on the ground; each system has its advocates, but there is probably very little or no superior advantage in the one over the other.

In first starting a blast furnace, great attention should be given to drying it thoroughly, and for this purpose fires should be lighted not only in the hearth but on the outside, if any damp is suspected to be hanging in the work. The fire in the interior should be gradually increased, the draught being regulated by means of a covering over the tunnel-head and filling-places, air being admitted at the fore-part as required. Too great a draught at first will raise too high a heat, and probably cause the work to fly and crack. When the furnace is considered to be sufficiently dry, fuel may be gradually added to the fire, until the furnace, or "stack," as it is technically termed, is half-full, care being taken that the fuel has burned red before another supply is added: this is to prevent so great an accumulation of gaseous matter as to cause explosion. The ashes and refuse are removed from time to time at the fore-part of the stack. When the stack is about half-filled with burning fuel, some blast-furnace cinder, if it can be procured, may be mixed with the succeeding charges of fuel, until the stack is two-thirds full, when slight charges of mine and limestone may commence, say in about half the quantities that would be employed after the furnace is fairly at work. The use of the cinder mentioned above, is that it shall when melted fill and warm the hearth before any metal is produced—iron frequently sticking and causing great trouble when it falls upon a cold hearth.

Air must be admitted at the fore-part by means of a kind of grate formed by placing bars of iron from front to back of the hearth, these bars being supported upon temporary brickwork so as to be about 20 or 25 inches above the bottom of the hearth, thus affording opportunity for removing ashes, &c., as they accumulate.

The tuyeres having been adjusted, and their water-pipes connected and supplied with water, and the blowing-engine in readiness, so soon as the approach of the cinder is known by its commencing slightly to drop into the hearth, the ashes collected in the hearth are rapidly cleared away, the bars and brickwork removed, the dam-stone bedded, and stoppings placed under the tymp and in the tapping-hole. These arrangements being completed, the blowing-engine is set in motion and the blast admitted to the furnace.

The filling with a reduced charge of mine and limestone, or "burden," as the ironstone and flux is technically called, is continued, and if all goes on well the burden is gradually increased. The cinder melts and falls into the hearth, the iron of the first charges soon follows, and the cinder rises to the "cinder notch" in the dam-stone, and flows down the fald. It is not usual to tap the furnace for some hours, (the time depending upon a variety of circumstances, as the capacity of the hearth, the number of charges, &c.,) as the quantity of iron made will be but small, and it is desirable to get the hearth well warmed at first starting. The cinder that is first produced from the burden is generally of a brownish or greenish hue—occasionally black or nearly so—but if all goes on well it soon becomes lighter in colour, with occasional streaks of deep blue. As soon as it is deemed that sufficient iron has accumulated, the stopping in the tapping-hole is cut away, and the metal is guided into the moulds formed in sand on the floor of the casting-house—the main runner from the furnace being termed the "sow," and the smaller branches are denominated "pigs."

After the metal has run out, some portion of cinder follows, and its expulsion is aided by continuing to keep the blowing-engine in motion: this is continued for a few minutes, when the engine is stopped to allow the furnace-man or "keeper" to clear out the ashes and refuse, and put fresh stoppings under the tymp and in the tapping-hole; after which the blast is again admitted and the operation of the furnace proceeds.

Before the engine is stopped the plugs to the sight-holes in the tuyeres should all be removed and left out, not only during the operations of the "cast," as tapping the metal is called, but they should not be restored to their places until after the engine has again been put in motion for the purpose of supplying the blast to the furnace: the reason for this mode of proceeding is to prevent the entry of gas from the stack into the blast-pipes, in consequence of a partial vacuum forming in the pipes when the engine is stopped, for unless air is admitted into the blast-pipes at the plug-holes, gas will enter the pipes from the furnace, and after mixing with the portion of air they contain, or the air supplied from the blowing-cylinder when the engine is again set in motion, will be forced in a highly explosive condition upon the burning fuel in the furnace, and violent explosion will instantly take place, sometimes with such destructive force that not only have the blast-pipes been burst, but the blast regulator, connections, and fittings, have shared the same fate, entailing heavy loss and interruption to the works.

At the time of replacing the plugs the nozzles should be examined to see that they are clear, and the combustion of the fuel vivid, or, as it is usually termed, "the tuyeres are bright."

The operation of casting is in all instances as just described—the iron being tapped twice, thrice, or more times, during the twenty-four hours, according to the size of the furnace, or capacity of the hearth, or according to the "rate of driving," i. e., the quantity of blast forced into the furnace, and the number of charges or quantity of burden and fuel filled into the stack. When a moderate quantity of blast is supplied, it is called "driving slow," or gently, but when a large supply of blast is forced into the stack, it is called "driving hard."

The tuyeres must have constant attention to see that a flow of water is maintained through them, the cold water being supplied from a head of about 20 to 30 feet in height and to the lower part of the tuyere, the heated water being taken off at the upper part. Attention must also be given to keeping the tuyeres open and bright, and in case of cinder or iron adhering to a tuyere, it should be immediately cleaned off. The spaces between the tuyeres and sides of the tuyere-holes, and between the tuyeres and the nozzles, should be kept stopped up, and no blast should be allowed to escape to waste under the tymp.

Wrought iron water-tuyeres are the best, and are now commonly used.

When a furnace is once well started and judicious management given in conducting its operation, very little difficulty should arise, but constant careful attention must be unremittingly afforded. One chief disturbance in smelting operations, is the occasional adhering of masses of half-melted materials to the lining of the furnace, preventing that even, gradual, descent of the materials so necessary to a furnace acting properly; sometimes these masses fall several feet, throwing the fire, hot cinder, and iron out under the tymp, and causing much disorder to the action of the furnace. These hanging masses are denominated "scaffolds," and when they occur, and cannot be dislodged from the filling-place or tuyere openings, it is necessary to lessen the burden of mine and melt them out, or even "blow down," i. e., melt out the contents of the furnace without putting in any fresh burden until the obstruction is removed.

The same stack, with the same description of materials, may be made to produce several descriptions or qualities of iron, according to the proportion of fuel employed in the operation of smelting: thus, when the fuel used is in large proportion to the burden, soft, tough, grey iron will be produced, but when the quantity of fuel is diminished to its lowest point, hard and brittle white iron is the result.

There are six varieties of pig-iron, known by the following numbers or names, viz.:

No. 1. Being the production of the furnace when charged with a large quantity of fuel in proportion to the quantity of ironstone. This iron is the most slowly made of all the descriptions of pig-iron, and contains a larger proportion of carbon, in chemical combination or mechanical admixture, than any other quality. It is the most fusible pig-iron and most fluid when melted, and is used for small and delicate castings. The fracture of this quality of pig shows a dark-grey colour, with high metallic lustre; the crystals are large, many of them shining like particles of freshly-cut lead. However thin this metal may be cast, if of good quality, it retains its dark-grey colour. This iron is the best description and the highest in price. The amount of carbon it contains is as much as from 3 to 5 per cent.

No. 2. Is intermediate in quality and appearance between Nos. 1 and 3.

No. 3. Contains much less carbon than No. 1. The crystals shown in a fracture of this iron are smaller and closer than in No. 1, but are larger and brighter in the centre than nearer the edges of the fracture. This is a strong iron when of good quality, and is sufficiently fluid for use in the foundry for large castings. A mixture of this with a proportion of No. 2 forms excellent foundry metal. The colour is a lighter grey than No. 1, with less lustre.

No. 4, or BRIGHT. This iron has a light-grey fracture and but little lustre, with very minute crystals of even size over the whole fracture. It is the "leanest," or contains less carbon of any of the grey irons. It is not fusible enough for foundry purposes, but is used in the manufacture of wrought-iron. It is the cheapest of the grey irons. When inferior in quality and nearly passing into the variety of pig-iron called "mottled," there is usually a thin coat or "list" of white iron round the exterior edges of the fracture.

MOTTLED, Is intermediate between No. 4 and White; the fracture being dull dirty-white, with pale greyish specks, and with a white "list" at the edges.

WHITE. This is the worst and most crude, hard, and brittle of the pig-irons; the fracture being metallic white, with but little lustre, not granulated, but having a radiating crystalline appearance. This iron is largely used in the manufacture of inferior bar-iron. It is sometimes produced by the furnace working badly, or is made by using a minimum of fuel with the ore and flux.

The principal chemical actions that take place in the process of smelting iron are these: the ore, in the form of oxide of iron, is heated in contact with carbon; the oxygen of the blast unites with the fuel to maintain combustion, and is converted into carbonic acid, and carbonic acid and also the aqueous vapour of the blast meeting with a large quantity of carbon at a very high temperature, are converted into carbonic oxide and hydrogen: the uninflammable carbonic acid, the product of combustion, dissolves or unites with a portion of carbon when passed through red-hot fuel, becomes doubled in volume, and is formed into inflammable carbonic oxide gas; the fuel also affording a greater or lesser supply of hydrogen. Carbonic oxide and hydrogen are the agents which deoxidize or convert the oxides of iron into metal. The reduced metallic iron passing down lower in the furnace comes in contact with an abundant supply of carbon, at a high temperature, with which it combines, and is converted into a fusible carburet of iron, the next stage of the process being, that the iron, the earthy matters, and the flux, meeting with a still higher temperature, are melted; the earthy matters and the flux together form a slag or cinder, and the melted iron and slag fall into the hearth or crucible of the furnace, where they arrange themselves according to their specific gravity, the iron taking the lowest place in the hearth and the cinder collecting on the top of it, until it accumulates to such a height as to pass away from the furnace by flowing out over the dam-stone.

Where a very pure oxide of iron is heated in contact with carbon, the carbon combines with the oxygen, thus reducing the iron to the metallic state, but as most of the ores of iron contain large quantities of earthy ingredients, it is necessary to make arrangements for their entire separation, and this is done in the blast furnace by the addition of some substance which will unite with the earthy portion of the iron ore, and form a more or less fusible compound. The substance added for this purpose is called a flux, and its mode of action is explained in the chapter on fluxes.

The operation of deoxidizing iron ores by heating them in contact with carbon is a process of some nicety—if the heat is insufficient the operation will not succeed—if the heat is too great or too suddenly applied, the materials will fuse into a slag or cinder, and become nearly or wholly unmanageable. What is required is, first, a gentle heat to expel the water, carbonic acid, &c., then an increase of temperature, but not amounting to a melting heat, while the deoxidizing process is proceeding. After the iron is reduced to a metallic state, the particles may be made to adhere together in the form of wrought-iron, or the metal may be further subjected to saturation with carbon, and it will then pass into carburet of iron or cast-iron. What is termed "working too fast" at a blast furnace consists in carrying the heat too high up in the stack, and thus melting the materials into slag or cinder, instead of producing such a temperature as will allow of the proper gradual chemical actions taking place.

The hottest part of the furnace must be at the tuyeres, the heat gradually decreasing upwards, so that the throat of the furnace may be comparatively cool,—for if a furnace is too hot at or near the filling-place, the mine will become fused before it has been sufficiently acted upon by the reducing gases, and the iron and earthy matter in combination, will run down towards the tuyeres in the form of a slag, from which but little or none of the iron will be revived, and the metal will be carried away in the cinder, instead of passing into the hearth in the form of carburet of iron. A furnace too hot at the top will not produce good grey iron, and will also cause more or less loss of metal. A dark cinder is usually the effect of carrying the heat too high up in the stack, and when observed the rate of driving must be slackened.

The difficulty of smelting grey iron from forge and mill cinder is in great measure owing to the density and compactness of such cinder; this compactness prevents the reducing agents in the stack from acting upon the interior portion of the fragments or masses of cinder, the consequence is that the iron the cinder contains is not reduced or revived into a metallic state, but remains in the form of oxide of iron combined with the silica and other impurities of the cinder. If the iron became revived, and was then subjected to the action of carbon at a sufficiently high temperature it would take up carbon and form grey iron; but forge cinder, in addition to being very compact, is very fusible; it becomes melted high up in the stack, and even supposing that a considerable portion of its iron were revived in the consequently rapid passage of the fused cinder through the stack, the iron so revived will not have been exposed to the action of carbon sufficiently long to form grey iron, but will arrive at the tuyeres in the form of a very crude, poor white iron.

A furnace may be too cool at the top as well as too hot;

where a furnace is too cool in the upper portion the mine will not be sufficiently heated, and the reducing gases will be of too low a temperature to thoroughly revive the metal from the ore at a proper height in the stack, and the metal that is reduced will be brought before the tuyeres in the form of white iron for want of being sufficiently long in the carbonizing region of the furnace: loss of iron will also take place by a portion of the oxide not being reduced, and therefore passing off in the cinder.

Rich ores are not so entirely advantageous and profitable for smelting iron cheaply, as might at first sight be supposed; a main item of cost in iron-making is fuel, and as ores require a consumption of fuel in their deoxidation and subsequent saturation with carbon, in proportion to their richness, no great saving is directly obtained in this important item of cost solely by the use of rich ores. Difficulty is found in smelting rich ores on account of their compactness and solidity, which prevents their being readily acted upon by the reducing gases, more especially the interior portion of fragments and masses of the ore, rendering it necessary to expose it to deoxidizing influences for a considerable time, and thus requiring the consumption of even a larger quantity of fuel than would have been needful had the same quantity of metal been dispersed through twice the amount of porous foreign material, thus making the ore only one-half as rich. Indeed, from some rich and very compact ores it is impossible, or nearly so, to produce grey iron. At the same time very poor ores are not profitable, because in smelting them a large quantity of fuel is consumed in heating the foreign substances accompanying the metal to a sufficient degree, a large quantity of flux is required, a corresponding production of cinder taking place, and the labour at the furnace increased; and not only so, but the cost of raising the stone, calcining and filling, as well as royalty and other charges, will run high on each ton of iron smelted. The attempt to smelt rich ores with a small proportion of fuel, or to hurry the process by "driving hard," causes the ore to melt before it is sufficiently deoxidized, a large quantity of hot, liquid, dark cinder is produced, great waste of metal takes place, and such small yield of iron as is obtained is of bad quality.

Ores of average richness are the most advantageous, and the best and most economical way of using rich ores is to add small quantities to furnaces in which average or poor ores are being smelted, as under such circumstances there is usually sufficient unemployed carbonic oxide to revive the iron in the small portion of rich ore added, thus increasing the make of iron without augmenting the charges of fuel—the proportion of rich ore being gradually increased to such a point as to produce the largest yield of metal without deteriorating its quality.

The secret of smelting iron cheaply is to arrange operations in such manner as to usefully employ as large a portion of the carbon of the fuel as possible in the stack; to use all the gaseous products from the furnace in heating the blast and raising steam; to mix the ores and flux available so as to have no fuel consumed in making unnecessary cinder, and keeping the yield of iron at its highest possible point without deteriorating its quality.

The principle upon which the mixing of ores, (usually made a matter of deep mystery, or hap-hazard,) should be conducted is simply this:—The earthy ingredients combined with iron ores are generally silica and alumina, with more or less magnesia, lime, &c., and, as more fully explained in the section on fluxes, these substances combine with each other, producing more or less fusible compounds; the greater the number of bases entering into the formation of a silicate the more fusible such silicate becomes; the use of a flux being to promote, by the addition of another base, the more easy fusion of the earthy materials. Now it is desirable to use as small a quantity of flux as possible, and much may be done to this end by the judicious mixing of different ores. For instance, suppose an ironstone containing a large quantity of alumina is being smelted, and that argillaceous limestone is used as a flux, the cinder being very tough and infusible; no addition of other ores also containing large proportions of alumina will alter the nature of the cinder, but the addition of silica, and, if possible, either in the form of a silicious limestone or of iron ore containing a large quantity of silica, is what is needed. With a silicious ironstone, ore containing alumina or magnesia should be mixed, and an argillaceous limestone used for flux.

It frequently happens that only one quality of limestone can be procured, and it is highly desirable to learn its composition, so as to be in a position to mix the ores available in the most favourable proportions. Sufficient attention is not usually paid to the nature of the limestone employed, although it is evident that it is a question of great importance: no substance should be put into the furnace except such as have a definite duty to perform; the natural constitution of ores and limestone prevents this from being rigidly carried out, but by judicious mixtures of ores of various known composition and degree of richness, and having due regard to the quality of the limestone used, it frequently happens that a very near approximation to a correct systematic operation can be made, and is the object to be kept in view in arranging mixtures of ores.

The following particulars of the quantities of the materials used in different localities for the production of one ton of pig-iron, will give a concise and clear view of the proportionate cost of labour, fuel, and ore, in the production of pig-iron: at the same time it must be borne in mind that as the cost of various descriptions of ironstone varies from 4s. or less, per ton, in some localities, to 20s. or more, per ton, in others, and as the value of labour, fuel, &c., is equally variable, it is probable that scarcely at any two works will all the materials be procurable at exactly the same proportionate rates:

COLD BLAST PIG-IRON.—STAFFORDSHIRE.

	£	s.	d.
2½ tons ironstone at 17s., . . .	£2	2	6
2 tons coal at 8s., ...	0	16	0
1 ton lumps at 6s. 6d., . . .	0	6	6
1 ton fine slack	0	2	6
Labour, ...	0	7	0
Rent, ...	0	1	0
Limestone, 12 cwt., ...	0	2	0
	£3	17	6

Cold blast pig-iron is usually 15s. per ton higher in price than the same description of hot blast pig-iron.

HOT BLAST GREY FORGE PIG.—DERBYSHIRE.

1½ ton of coke at 10s.,		£0	15	0
Ironstone, 3 tons, long weight, at 8s.,		1	4	0
15 cwt. limestone,		0	3	4
Coal for blowing-engine (non-condensing) 7½ cwt.,		0	1	2
Coal for calcining ironstone	(per ton of pig-iron),	0	1	0
Labour throwing up in heaps and calcining ironstone,	ditto,	0	0	7
Breaking limestone and riddling mine,	ditto,	0	0	4
Engine-tenting, 5d., oil, black-lead, &c., 1d.,	ditto,	0	0	6
Furnace-keeping and moulding pig-beds,	ditto,	0	0	8
Filling,	ditto,	0	1	0
Getting out metal, weighing and stacking,	ditto,	0	0	2½
Hauling cinder,	ditto,	0	0	4½
Repairing tools,	ditto,	0	0	1½
Superintendence,	ditto,	0	0	3½
Cost per ton,		£2	8	7

One hundred tons made per week from one furnace; the blast heated by means of flame from the furnace; furnace blown with four tuyeres.

HOT BLAST WELSH CINDER PIG-IRON.

Average quality being one-fifth foundry-iron, and four-fifths grey forge, mottled and white.

3 tons of coal (coked), at 5s. 6d.,	£0	16	6
2 tons ironstone, at 10s.,	1	0	0
17 cwt. forge cinder, say,	0	5	0
8 cwt. limestone,	0	1	4
Coal for hot blast and blowing-engine,	0	2	9
Wages, including furnace-men, fillers, cokers, engine-tenters, labourers, getting out iron and hauling cinders, and superintendence,	0	7	2
Cost per ton,	£2	12	9

Furnace producing 125 tons weekly, and a portion of the gases used in assisting to raise the steam and heat the blast; the ironstone containing a considerable admixture of limestone and calcareous spar accounts for the small quantity of limestone required; furnace blown with five tuyeres.

WELSH ANTHRACITE IRON.

	Cwts.
Anthracite coal,	36·54
Welsh ironstone,	41·76
Lancashire ore,	2·60
Calcined Cornish ore,	1·00
Limestone,	14·34
Coal for boilers,	23·40
Coal for hot blast ovens,	12·00

Materials for one ton of pig-iron; furnace produced 50 tons of pig-iron per week; blown with nine tuyeres.

WELSH ANTHRACITE IRON.

	Cwts.
Anthracite coal,	35·50
Welsh ironstone,	36·00
Lancashire ore,	2·80
Cornish ore,	3·55
Brixham ore,	2·30
Limestone,	15·40
Coal for boilers,	29·70
Coal for hot blast ovens,	11·20

Materials for one ton of pig-iron; make of iron 50 tons per week; furnace blown with nine tuyeres.

COMMON SCOTCH PIG—HOT BLAST.

32 cwt. black-band ironstone.
45 cwt. splint coal.
16 cwt. cinder and dross.
7 cwt. limestone.

Materials for one ton pig-iron; labour at furnace, 5s. per ton.

When puddling and mill-furnace cinder is used in the blast furnace, it should be broken small and mixed with the other materials and flux; this will partially obviate the bad effects of using such cinder, which has a tendency to melt in the upper part of the furnace, and run down into the hearth without the iron it contains being thoroughly deoxidized.

Puddling and mill-furnace cinder frequently contains sulphur and phosphorus, and in some cases it is usual to calcine the cinder before filling it into the blast furnace.

Black-band ironstone, when consisting mainly of carbonate of iron and carbonaceous matter, may be advantageously smelted in the blast furnace raw as raised from the mine, without being calcined, and will furnish good grey iron very readily, and in cases where the black-band is usually calcined before being put into the blast furnace, it is not unusual to add a portion of the richest and purest black-band in a raw state to the other materials.

The large outlay required for the erection and maintenance of blast furnaces, and the necessary blowing machinery, has caused considerable attention to be given to the endeavour to smelt iron by some other process not requiring such extensive and costly appliances. The old method of manufacture in the charcoal fire or Catalan forge has already been adverted to, and its disadvantages pointed out, and various other processes for making wrought-iron direct from the ore have been suggested, among which are one or two recent American inventions; their main objects being to avoid the necessity of such expensive structures as blast furnaces, and also to conduct the operation of reduction of the ores, so as to employ a minimum of fuel. The system upon which the operation is proposed to be conducted is, to grind the ore fine, and to thoroughly mix with it a suitable proportion of small coal or other carbonaceous matter; this mixture is then subjected to heat in vertical fire-brick chambers, 12 or 14 inches in width, of any convenient length, and several feet in height, the walls being only 3 inches in thickness; the heat is supplied from a fire at the foot of the chambers, the flame acting on the *outside* of the chambers, so that their contents are gradually heated *through the brickwork*, for if heat were directly applied to the contents of the chambers, the ore would simply become fused and clinker together. After the contents of the chambers have undergone sufficient cementation, and the iron of the ore becomes reduced to a metallic state, it is removed at the base of the chambers, and falls into a reverberatory furnace, where it is heated, until the particles of metal adhere together, when it is transferred to the puddling-rolls or shingling-hammer. The supposed advantages being saving of outlay in erections; economy of fuel, as no more carbonaceous matter is to be used than just sufficient for the deoxidation of the ore, and that therefore no waste would occur; saving of labour, and celerity of manufacture. These advantages, however, were not borne out in trials of the American process on a fair scale, conducted in this country. The iron produced was in very small proportion to the extent of apparatus required, the quality indifferent, and upon any endeavour being made to produce a quantity of metal at all approximating to what was necessary to make the system commercially available, the quality was so bad as to be wholly worthless; and consequently the erections necessary to operate upon any large quantity of material would be as heavy or more so than are required for smelting the same amount of metal by the usual method with the blast furnace. The labour and consumption of fuel was also very considerable, and the grinding of ironstone and coal on a large scale would be exceedingly tedious and expensive. The iron also never being melted by this process, there is not the same opportunity of getting rid of the earthy impurities as is afforded by the blast furnace:—this and similar methods of procedure (for which numerous valueless patents have been secured) may be well enough adapted to localities where but a small demand for iron exists, and where rich iron ores can be procured, but they are wholly unsuited for extensive operations. The large quantity of material that can be operated upon in the blast furnace, and the regularity in quantity and quality of the iron produced by the process when properly conducted, are such as completely outweigh the supposed advantages of any of the methods yet proposed for obtaining malleable iron direct from the ore.

The following mention of an early attempt to manufacture iron by the use of coal in a kind of reverberatory furnace, and also notice of the manufacture and use of coke for fuel at ironworks, is made by Henry Horne in his 'Essays concerning Iron and Steel;' London, 1773.*

---

* "A few years since I spent several months at a friend's in Shropshire, where I was informed several of these attempts [to manufacture coke] had been made, and where at that time great quantities of this kind of fuel

[charred pit coal] were made use of in order to run down pots and kettles, as well as larger works, such as cylinders for fire-engines, &c. Among other information which I was able to pick up in that part of the country, I met with a tradition that a famous Dutchman had made his appearance in that neighbourhood many years ago, under the character of a great connoisseur in the smelting of iron-ore with pit-coal: this person being thought to have a considerable share of knowledge in this way, his proposals were eagerly embraced by some of the iron-masters, and no pecuniary assistance was refused him, in order to put his scheme in execution. A very costly furnace was erected for the purpose; much more so than it need to have been, had the projector went upon true and genuine principles. But unhappily, he had somehow or other imagined that the flame issuing from the fuel, because it put on a clear and splendid appearance, must be pure enough, could it be conveyed to the ore with sufficient strength, to be a proper dissolvent of it. To effect this (as far as I could procure any tolerable account of the structure of the furnace, which for many obvious reasons must have been a draught one) the flame was by various turnings and windings to have been so urged on, and directed by the force of the air as to terminate in strong and powerful focuses against the body of the ore; so as to have procured a dissolution without any of the gross parts of the fuel coming in contact, or having any immediate business in the operation.

" Had the Dutchman better understood the nature of our mineral fuel, he would never have supposed that the flame could by any means have furnished a pure or proper dissolvent of the iron ore; his ignorance in this respect defeated his project, as the metal separated by this method discovered such extreamly bad qualities as rendered it absolutely unfit even for the most ordinary purposes. This ill success soon issued in the breaking up of the scheme, and the demolition of a very curiously constructed furnace."

BLAST.

SOME idea may be formed of the immense quantity of air required in smelting iron, from the following calculations: A blast furnace making 17 tons of grey forge pig-iron in 24 hours, will require about 68 tons of solid materials, viz., calcined ironstone, limestone and coke, to produce that quantity of metal. The blast will require to be supplied at a pressure of from 2 lbs. to 3 lbs. per square inch above the atmosphere, at the rate of 4,000 cubic feet per minute, and heated to about 612° Fah., and the weight of air thus forced in will, in 24 hours' time, amount to 200 tons, or three times the weight of all the solid materials. With this quantity of blast there will be driven into the furnace about 2 tons weight, or 450 gallons of water, derived from the watery vapour in the air; 94,000 cubic feet of hydrogen gas, weighing 4·44 cwt., and 47,000 cubic feet of oxygen gas, weighing 35·56 cwt. are necessary to form this quantity of water, the steam from which is decomposed on entering the furnace, setting its constituents at liberty to form fresh combinations.

Blast furnaces were blown with air at the ordinary atmospheric temperature until about the year 1830, when J. B. Neilson reduced the use of the heated blast to a successful practical application at the Clyde ironworks in Scotland. It may readily be conceived how great an amount of prejudice and opposition had to be overcome in the introduction of the use of the heated blast, when it is considered that it was formerly supposed that the colder the blast the more advantageous it was for iron-smelting; this opinion having been formed from the observation that furnaces blown with air at ordinary atmospheric temperatures, worked better and yielded more iron in the winter than in the summer season. This circumstance being due to the superior density of the air in winter time, the warm air of summer being more rarified, and containing a greater amount of watery vapour which requires the absorption of a portion of the heat in its conversion into steam.

Neilson's experiments having proved the important advantages of a hot blast, its use has gradually extended, until at the present time it has nearly superseded the use of cold blast. The hot blast saves one-half and upwards of the fuel that would be required if a cold blast were employed, besides producing other important beneficial effects in the working of the furnace; and when properly and judiciously used, without in any way interfering with the quality of the iron, notwithstanding the great feeling of prejudice against the use of hot blast iron that existed for a long period after its introduction.

The mode of action and effects of the heated blast are as follows:—A current of air, of usual atmospheric temperature, under pressure, upon being passed into the furnace, cools the fuel upon which it directly impinges below the temperature necessary to effect the union of the carbon of the fuel and the oxygen of the air; whereas, when a heated blast or current of air is employed, the temperature of the carbon is not reduced below the point at which it readily unites with the oxygen. The different effects produced by these two arrangements are much greater than would appear probable at first sight.

In using a cold blast, the air on entering the furnace abstracts caloric from the burning fuel, thus lowering the temperature of the furnace at the point of contact of the blast, and also chilling the cinder, but causing vivid combustion after the air becomes sufficiently heated;—in the case of heating the blast before it is supplied to the furnace, it is forced on the fuel in a condition favourable to its uniting immediately with it, causing at once vivid combustion, preventing a reduction of temperature, and not chilling the cinder.

It might be supposed that an equal quantity of fuel would be consumed whether the air were heated in the furnace or before being forced in, but this is not so.

It is necessary that a blast furnace, to be in good working condition, should have its highest temperature at or near the tuyeres, the temperature gradually decreasing upwards towards the tunnel-head: when the blast is supplied in a heated state, say at 600° Fah., it immediately combines with the fuel at the tuyeres, causing vivid combustion, and production of carbonic acid; but if the same quantity of blast were forced in cold, say at 60° Fah., a large portion of it would not combine immediately with the fuel at the tuyeres, but would be forced a greater or lesser distance upwards in the furnace, becoming heated in its passage, and uniting with the fuel there, would cause a more elevated temperature than necessary and advantageous, thus consuming fuel needlessly, and rendering it imperative to fill into the furnace sufficient fuel to allow of a portion being wastefully consumed by the blast passing upwards in the stack, and yet also for so much fuel to remain unconsumed as will be required for sustaining the process of melting the slag and metal when the burden arrives at the tuyeres; for if too large a proportion of the fuel be consumed at some distance above the tuyeres, the burden will sink downwards towards the hearth without the needful supply of fuel accompanying it, and a total disturbance of the operations of smelting take place; the iron produced being white, of bad quality, and small in quantity, owing to a large portion of the metal passing away in the cinder, which will be dark-coloured, or even black, the furnace in fact working "too fast." The remedy for this is to diminish the quantity of blast or "work slower," but even then there is always the same tendency for a large proportion of the air to unite with the fuel too high up in the furnace, causing the disadvantageous consumption of a large quantity of fuel.

The above explanation of the action of a "cold blast" at the blast furnace shows the necessity of adopting "cold blast burden" where a heated blast is not employed; a "cold blast burden" consisting of a much smaller quantity of mine and flux in proportion to fuel than hot blast burden. It is true that a hot blast furnace may be thrown on a dark cinder and white iron by supplying it with a much larger quantity of air than can combine with the fuel at the tuyeres, but there is not the constant tendency in a heated blast for a large portion of it to unite with the fuel at too great a height in the furnace, as is the case with a cold blast.

Besides the important advantage of causing great economy of fuel, the use of a heated blast produces other beneficial effects. A cold blast chills the cinder around the tuyere, and without constant attention the tuyere would become closed or "brigged up," and the blast become intercepted; but with a hot blast the cinder is always maintained in a fluid state, and the work about the furnace much reduced: and when in addition to saving of fuel, and ease in managing the furnace, something like double the quantity of pig-iron can be made from the same furnace in the same time by the use of hot blast than could be made by cold blast, the immense advantages of a heated blast are clear. The reason of the increased make of iron with the hot blast being that the heated air combining readily with the fuel at the tuyeres, the furnace "works faster" with a hot than with a cold blast; and as there is much less tendency for hot blast to give rise to untoward action in the furnace than cold blast, through combining with the fuel at too great a height above the tuyeres, a hot blast furnace may be pressed considerably more than a cold blast furnace will bear without causing disarrangement of its operation: the action of the hot blast upon the cinder has also considerable and favourable influence.

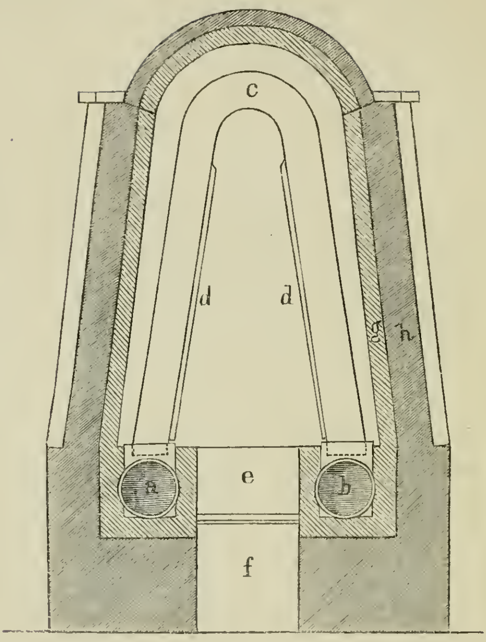
The temperature to which the blast is heated before being forced into the furnace varies in different cases, but about 612° Fah. is that usually employed, and it is probable that no additional benefit would accrue from using a blast at a much or any higher temperature. It is found in practice that a blast heated to 612° fulfils the conditions of a portion of it uniting rapidly with the fuel at the tuyeres, without chilling the cinder, but still allowing some air to pass upward in the furnace so as to maintain a sufficiently active combustion in the upper part of the furnace; now suppose that the blast were heated to such a temperature that the *whole* of the air united with the fuel *immediately* on its entering the stack, the consequence would be the production of carbonic acid, and combustion in the upper part of the furnace would be smothered. A few strokes of the blowing engine with the blast at an extremely high temperature would probably be productive of no very serious inconvenience, but if continued, the effect would be to rapidly consume the incandescent fuel, and melt out the iron and flux in contact with it, and thus to bring down a further supply of material from the upper part of the furnace before it was in a proper condition, and thus to make bad work in the furnace: if the use of the extremely heated blast were persevered in, the contents of the furnace would be all melted up together into slag; and this extreme heating of the blast would amount to driving too fast.

There is also another difficulty that would have to be encountered in employing a blast of much higher temperature than that usually had recourse to, and that is the destruction of the apparatus for heating the blast. In practice, with present arrangements, it is usually sufficiently difficult to maintain the heat up to the necessary point, and even at this temperature the destruction of apparatus is very considerable, and would increase at a rapid rate if a much higher heat were employed.

The stoves or ovens for heating the blast are constructed very variously; the most usual method consisting of an inlet and outlet main, or cast-iron pipe, laid horizontally, and provided with a number of sockets into which are fitted "arch" or connecting pipes, for conveying the blast from the one main to the other. Both the mains and connecting or arch-pipes are enclosed in a brick oven or stove, and are heated by a grate. Fig. 8 is a section, and fig. 9 a plan of a hot blast stove, to a scale of one quarter of an inch to the foot.

a. is the inlet main by which the cold blast from the blowing engine enters the stove.

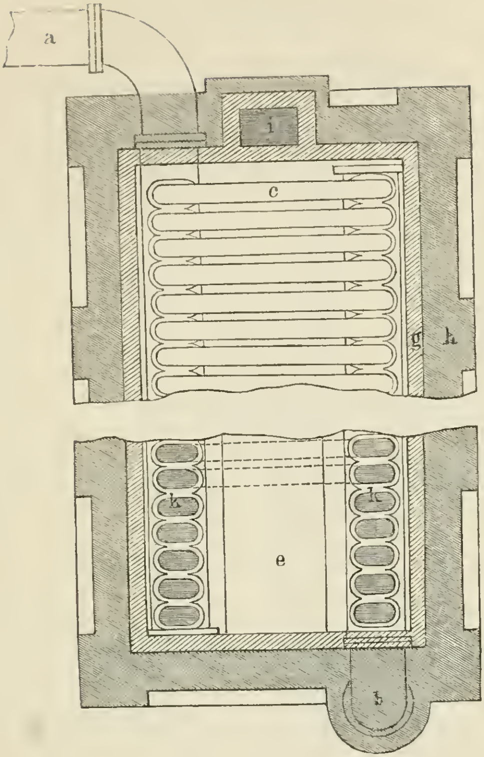
Fig. 8.



b. is the pipe conveying the heated blast to the furnace.
c. the arch or connecting-pipes; and
d. d. are flanges or ribs cast on the arch-pipes to assist in strengthening them, especially in the event of any tendency to sink from being overheated.
e. is the grate; the area of which should be about 10 square feet for each 1,000 cubic feet of blast required to be heated per minute; but this will depend to some extent on the nature and quality of the fuel used.
f. is the ash-pit.
g. fire-brick lining.
h. external brickwork.
i. flue, which should be connected with some sufficiently high chimney to obtain a proper draft.
k. k. sockets into which the ends of the arch-pipes fit.

The main pipes must be protected from the direct action of the fire by being cased with thin brickwork, the blast being mainly heated by coming in contact with the heated internal surface of the arch-pipes, as it passes, by means of the

Fig. 9.

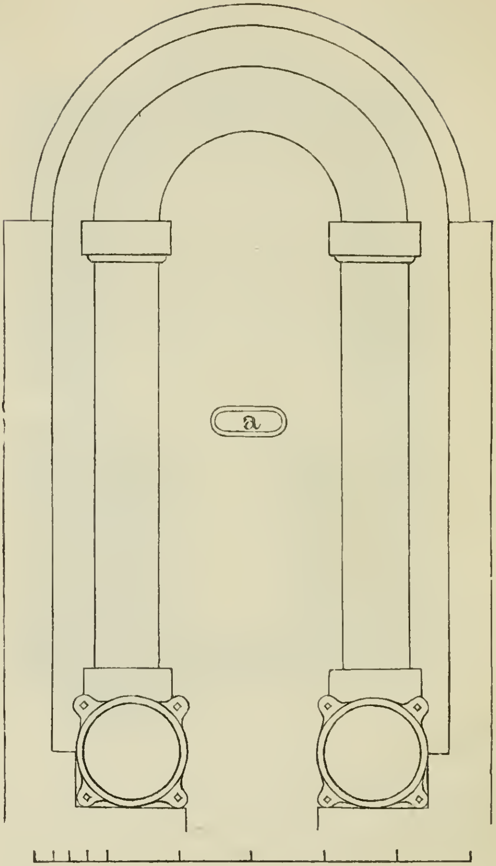


constant pressure from the blowing-engine, from the inlet to the outlet main.

The arch or connecting-pipes are frequently circular, but pipes of an oval, elliptical or oblong section are now usually preferred, on account of the blast being brought more immediately into direct contact with the heating surface than is the case with circular pipes. Fig. 10 shows a good method of constructing the arch-pipes; the vertical pipes and circular portion being cast separately from each other. a. is a section of the pipe.

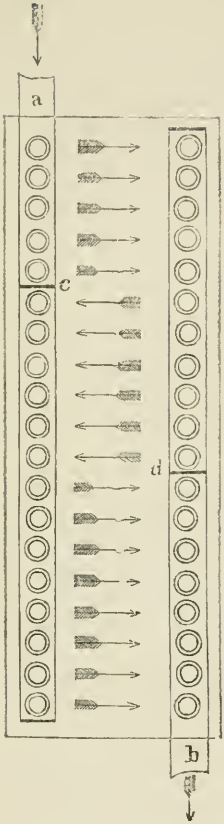
In some cases, the blast to be heated is not simply admit-

FIG. 10.



ted by one main and passed directly into the other, as just described, but is conveyed from side to side of the oven, so as to more completely bring it into contact with the heating surfaces; thus, as shown in fig. 11, the cold blast is admitted by the main a, and, by the first five pipes only, is passed to the main b, the stopping at c preventing the blast passing further in that direction. The blast is then returned from

FIG. 11.



main b to main a, by six pipes, another stopping at d preventing the blast from proceeding any further in that direction; the blast is now finally returned through eight pipes to main b, by which it is conducted to the furnace.

The cold blast should always be made to enter the pipes at the coolest part of the stove, and be taken direct to the furnace from the hottest part.

Hot air ovens are frequently constructed with the pipes of considerable height in proportion to the length of the oven; the consequence is, there is a rapid and direct draft to the chimney or outlets for the smoke, and great waste of fuel is incurred, as may be seen by the volumes of dense black smoke or flame that usually escape from the chimneys of such ovens. If the pipes were made of less height, and increased in number, and the oven consequently lengthened, a better opportunity would be afforded for burning the gaseous products of the coal, and for the introduction of stoppings to direct the flame and heated air advantageously, and both fuel and labour would be economised.

The surface of pipe necessary to heat a certain quantity of blast in a given time, varies exceedingly according to the construction of the heating apparatus; but perhaps, as a pretty near average, 400 square feet area of cast-iron pipe exposed to the action of the oven fire, may be stated as about the extent of surface necessary to heat 1,000 cubic feet of blast per minute. There are cases in which the extent of heating surface is considerably less than this, and many in which it is exceeded, but where only 350 square feet of surface are used to heat 1,000 cubic feet of blast per minute, it may be concluded that the apparatus is well arranged.

In a well-constructed oven, heated by waste flame and gases from the blast-furnace, the surface of pipe exposed to the action of the flame was 1,640 square feet, the quantity of blast heated being about 3,600 cubic feet per minute, thus requiring 45·5 square feet area of heating surface for each 100 cubic feet of blast per minute. The area of the internal surface of the pipes, with which surface the blast came in contact, was 1,340 square feet, equal to 37·25 square feet of internal surface of pipe to heat 100 cubic feet of blast per minute; or 12·19 square feet of internal heating surface for each ton of grey forge pig-iron produced. It should be mentioned, that in making the above calculations, the surface of so much of the inlet and outlet mains as was affected by the heat of the oven, was added to the area of heating surface. This instance should go far to remove the great prejudice that is sometimes met with against the use of waste gases on account of their low heating power.

The quantity of blast necessary to produce a certain amount of pig-iron in a given time, will depend on a variety of contingencies: as an approximation, under favourable circumstances of ore, fuel, work, &c., 4,000 cubic feet of blast per minute will produce 120 tons of grey forge pig-iron per week.

When a cold blast is used, it is conveyed from the supply pipe into the furnace through a leathern pipe provided with an iron discharging nozzle; this arrangement allows of the pipe being readily removed for inspecting the tuyere that forms in the cinder through the chilling action of the blast, the state of which requires constant attention, and the pipe can again be instantly replaced. The cooling action of the blast causes the cinder to become solid just where the blast is admitted, and by degrees a tuyere or pipe is formed in the cinder, which tuyere must be kept open, or the blast will not be able to enter the furnace: these cinder tuyeres are also liable to be burnt off or to fall off, and attention must immediately be given to their proper renewal.

The blast should be supplied to the furnace in a regular continuous current of equal pressure, and, to assist in promoting this object, a blast-regulator, or large vessel made of wrought iron plates, should be provided to receive the compressed air from the blowing cylinder, such regulator being fitted with a valve to allow a portion of the blast to escape whenever the pressure increases above a certain point. In cases where three blowing cylinders work from one rotatory motion a continuous current will be obtained without any regulator being necessary. The hot air ovens should have a roomy connexion with the blast regulator; and the pipes for conveying the heated air to the stack should be spacious enough to prevent any unnecessary friction to the passage of the blast; elbows, angles, and bends being as much as possible avoided, so that the blast may not be wire-drawn or throttled between the ovens and the tuyeres, but may be delivered freely and without loss of pressure into the furnace.

The pressure or "pillar of blast" usually employed, ranges from 2½ to 4 lbs. pressure, per square inch, above the atmosphere, depending upon the quality of the fuel, size of the furnace, &c. Too much blast causes a furnace to work "too fast," and too little blast causes a furnace to work "too slow." Too strong or too weak a blast causes a furnace to work badly as respects the quality and quantity of iron produced, and a large portion of a weak blast often finds its way up between the materials in the stack and the lining, producing intense heat, and burning out the hearth, boshes, and lining, instead of being forced into the centre of the materials and exciting an equal vivid combustion of the entire fuel in the neighbourhood of the tuyeres. But little good can be done at a furnace that is under power as regards blast.

Vertical, long-stroke engines and blowing cylinders are better adapted for the purpose of supplying blast than horizontal engines and cylinders; and blowing engines, to work advantageously and economically, should be of sufficient size and power to be able easily to supply the necessary quantity of blast, without being hard pressed, or run at a high speed.

High speed engines are to be avoided, for the cost of repairs to engines working at high speeds is well known to be very great, and they also consume a large quantity of fuel to produce a given effect. High pressure steam, used expansively and then condensed, will be most economical.

The experiment of blowing blast furnaces with the fan has been tried, but does not answer. There is great difficulty in procuring sufficient pressure or pillar of blast by the use of a fan, and the high speed at which a fan must be driven causes great expense and wear and tear in working.

Fans produce but little blast in proportion to the power employed to drive them, and the cause of so small an effect is usually stated to be the great loss of power arising from friction. The friction of a fan at a high speed is undoubtedly great, but the cause of so small an effect being produced by a fan may be more correctly attributed to the loss from the leakage inseparable from the construction of the apparatus.

Most modern blowing engines are provided with a fly-wheel; and although it may be objected that the fly causes the blowing piston to move at a higher speed at the middle than at the end of its stroke, and that the motion would be more uniform without the fly, still the momentum of the fly enables the blowing piston to finish its stroke and commence returning without the delay and loss of time, and consequently loss of blast, that is experienced in engines without a fly-wheel, especially when the steam happens to be a little lower than its proper working pressure.

The pressure of blast may be increased by using smaller tuyere-nozzles and increasing the pressure of steam at the blowing engine.

A soft fan-blast is most advantageous for a cupola for remelting iron for foundry purposes; large tuyeres and small pressure are most advantageous for the following reasons:—So long as sufficient air is supplied to cause thorough gradual vivid combustion of the coke, the iron in the cupola will be completely fused, with the consumption comparatively of a small amount of fuel, and nothing more than this is required:—but if the blast is forced in at a high pressure, a large portion of it will not combine immediately with the fuel, but will pass upward in the cupola and excite an unnecessary degree of activity of combustion in the upper part of the cupola, and burn away the coke before the iron mixed with it has sunk into the hottest part of the cupola near the tuyeres, the consequence being that a large quantity of coke must be charged with the iron, or else the iron will sink to the tuyeres without a sufficient quantity of coke accompanying it to cause complete fusion, thus causing waste of fuel. There is also another most important effect caused by supplying the blast at too high a pressure, and that is, the quality of the iron is deteriorated by the oxidizing influence of the blast, so that instead of procuring soft, tough, fluid, carbonized foundry iron with small expenditure of fuel, as is the case with soft fan-blast and large tuyeres—by using the high pressure blast the iron is decarbonized and rendered hard and brittle, and dies rapidly upon being run into the ladle—a large consumption of coke takes place, and the cupola also is rapidly destroyed.

The hot blast has in some instances been applied to cupolas for re-melting iron; but perhaps on the whole such application is a questionable benefit.

The usual method of ascertaining whether the blast is sufficiently heated, is by inserting the end of a small stick of lead into the plug-hole of the tuyere-nozzle. Lead melts at 612° Fah., and the blast is considered properly heated, or, as it is technically termed, "the heat is up," when the surface of the lead exposed to the action of the blast is melted, and the fused particles of lead are scattered by the force of the blast. When the blast is hot enough to readily fuse the surface of the lead the workmen say that "it takes the lead."

FUEL.

The best fuel for producing iron of great purity, and suitable for the finer purposes to which that metal is applied, is wood charcoal; and good coke, or charred bituminous coal, is the most suitable fuel for manufacturing iron of good useful qualities on a large scale, and is that generally used at British ironworks. Hard coal, not too bituminous or too compact, is the next in order of quality; stone coal or anthracite being, on account of its extreme compactness, an unsuitable fuel for smelting iron, as, owing to the difficulty with which it combines with the oxygen of the blast, its combustion proceeds so slowly that not more than from one-half to two-thirds of the quantity of iron can be produced by its use, in a given time, that could be made from a similar furnace using coke for fuel. Peat is valueless as a fuel for iron-smelting on account of the large proportion of water it contains, besides frequently having a large amount of earthy matter in its composition. The use of wood charcoal in Great Britain for the purpose of smelting iron, is at the present time confined to Newlands, and one or two other furnaces in the neighbourhood of Ulverstone, and Lorne works near Inverary.

Britain has abundant supplies of coal of every description of that valuable material, from the highly bituminous to the purest anthracite; the best coke for blast furnaces and similar purposes being made from the bituminous coal of the Durham coal-field, and from some of the lower seams of a portion of the southern edge of the South Wales basin.

Coking is usually performed in ovens, the charge of coal being fired by the heat retained by the oven after the previous charge has been drawn. The process consists in dissipating the volatile combustible ingredients of the coal, leaving a mass of carbon or carbonaceous matter, or "coke." Coke contracts by long exposure to a high temperature, and as it is necessary that blast furnace coke should be close, hard, and dense, the operation of coking should be slowly conducted; thus the necessity of having a large number of coking ovens at smelting works. The length of time necessary for obtaining good coke varies according to circumstances, but from sixty to ninety hours may be considered as a usual period for obtaining a dense coke from bituminous coal. The loss in weight the coal sustains by coking ranges from twenty-five to forty per cent. The red-hot coke is cooled by water being thrown over it from an engine hose, as soon as it is drawn from the oven.

At some furnaces the fuel consists of a mixture of coal and coke, and at the anthracite furnaces in South Wales the proportion of coke used sometimes amounts to as much as one-third of the fuel employed; the expense of bringing the coke from a considerable distance being more than counterbalanced by the increased make of iron. The Welsh anthracite furnaces, almost without exception, now use a greater or less proportion of coke mixed with the anthracite coal.

Highly bituminous coal in a raw state is unsuitable for use in the blast furnace, as it would cake or "crosil" together in masses, and prevent the regular descent of the burden; tender or soft coal is also unsuitable. Coal to be used raw for iron smelting should have considerable adherence of its particles, so as not to be easily friable; it should not contain much ash or bitumen, and should be free from sulphur.

Anthracite contains no bitumen, and will not form coke; some varieties of it are nearly pure carbon, and burn without producing any flame or smoke. It is so compact that, as before observed, the blast combines with it (and consequently its combustion proceeds) but very slowly; a fragment of anthracite procured from the fore-part of a blast furnace after having descended through the stack from the filling-place, if only of the size of a walnut, will frequently be quite raw in the interior. Anthracite upon being heated decrepitates to such a degree that the small fragments thrown off the exterior of the lumps form so much dust in the blast furnace, that it is necessary to maintain an opening under the tymp, and to allow a portion of the blast continually to escape for the purpose of blowing out the dust or small splinters of the fuel. Anthracite coal cannot be advantageously used for fuel at puddling or mill furnaces, nor in the blast furnace with a cold blast; even with hot blast the heat must be well kept up, and the make of iron will then be far below that of similar sized furnaces in which coke is used for fuel. The expenses for labour, &c., at stone coal furnaces are heavy in proportion to the quantity of iron produced, and the iron has no peculiar advantages in quality to compensate for the smallness of make.

FLUXES.

The necessity for the use of fluxes in iron-smelting having been already explained under the head of smelting, we will now advert more in detail to the description of the substances employed as fluxes in the blast furnace, and also to their chemical action.

The earthy matters usually combined with iron ores mainly consist of either silex or alumina, or of both combined in various proportions. Four of the earths, viz., lime, magnesia, baryta, and strontia, possess decided alkaline properties, and readily saturate the acids. Alumina, one of the earths proper, abounds in clay, and when uncombined is insipid and inert. Silica is really an acid, and forms compounds or silicates with the bases alumina, lime, magnesia, potash, soda, oxide of iron, &c., but silica being insoluble in water its acid properties are not usually manifested.

Dr. Ure states, that if either lime or silica be added separately to alumina in any proportion, the mixture will not melt in the most violent furnace; but if alumina, lime, and silica be mixed together, the whole melts, and the more readily the nearer the mixture approaches the proportions of 1 of alumina, 1 of lime, and 3 of silex: increasing the amount of silex renders the compound less fusible. Silicate of lime also is by itself very refractory.

We find in practice that considerable range in the degree of fusibility of cinder or slag may be obtained from the admixture of silica, lime, and alumina, in various proportions, but the capacity of saturation of silica is not known, so that the quantities of the bases required to saturate a given proportion of silicic acid cannot be exactly pre-determined.

The degree of fusibility of the compound formed from the earthy matters in the blast furnace is of great importance; for if it is much more easily fused than the iron itself, it will melt rapidly on approaching the tuyeres, and leave the iron exposed to the oxidizing action of the blast, and white iron will be the result, even although the iron may have been highly carburetted before arriving within reach of the action of the blast. To produce grey iron the cinder or earthy compound must be only a very little more fusible than the carburetted iron, so that the iron will be protected by it until the materials arrive before the tuyere, when the increase of temperature will cause the speedy separation of the iron and cinder as they fall into the hearth; at the same time if the earthy compound is too refractory, it will prevent the whole of the iron being melted out, and waste of metal will occur through a portion of the iron being enveloped in and carried away in the cinder; or waste may also take place from the tenacious cinder preventing the rapid passage of the metal to the hearth and detaining it while exposed to the blast, the consequence being that the iron becomes oxidized and unites with the cinder, instead of passing into the hearth in the form of carburet of iron.

The fusibility of the earthy matter or cinder depends in great measure on the number and variety of its constituents; thus, silicate of alumina is infusible, but by the addition of another silicate, that of lime, which is itself very refractory, a fusible double silicate of lime and alumina is produced, and the addition of silicate of magnesia or other alkali will render the compound still more fusible. Silicates dissolve or flux the metallic oxides; protoxide of iron forming with silica a very fusible compound or silicate of iron.

Fire clay is essentially a silicate of alumina. Seven parts of silica, six parts of aluminous earth, and two parts of an alkaline earth, produce the vitrified substance porcelain. The compounds of silica with excess of alkali are caustic and soluble; those with an excess of silica are insoluble, and form glass. When glass contains too much alkali it is partially soluble in water. The slag or cinder from the blast furnace usually consists of silica, alumina, lime, and oxide of iron, in various proportions, with the occasional addition of sulphur, magnesia, manganese, and other substances. Where much sulphur is present in the furnace it is desirable to use rather more lime than would be necessary as flux under ordinary circumstances, as the sulphur will combine with the lime and be carried off in the cinder.

Limestone is the material mostly employed as a flux in the blast furnace; chalk or calcareous spar is sometimes employed, and in cases where calcareous ore is being smelted the judicious addition of a suitable quantity of clay or sand as a flux may be highly advantageous.

Limestones vary extremely both in structural arrangement and colour, and equally as much in composition; some having large admixtures of bituminous matters, or sand, clay, oxide of iron, pyrites, magnesia, &c., in fact, to such an extent as to form a regular gradation from nearly pure limestone to calcareous shale, schist, sandstone, ironstone, &c.; and the object of the addition of lime to the mine and fuel being that it shall assist in forming a more or less fusible compound with the earthy matters in combination with the ore, so as to set the reduced iron at liberty to fall by its superior gravity to the bottom of the furnace hearth, and as it is in every way true economy to use no more flux than absolutely necessary, it is very important to ascertain the quality of the limestone employed for the purpose; for instance, in smelting an ironstone containing a large amount of silica, it would be very bad management to employ a silicious limestone, or in smelting ironstone combined with a large proportion of alumina, to use an argillaceous limestone; again, a calcareous ore may require little or no addition of lime as a flux.

The use of quicklime in the furnace instead of limestone has been at times highly recommended; but it would seem that no particular advantages have resulted from doing so, and the flux is almost universally added in the form of limestone or chalk.

It is obvious that no exact rule can be laid down for the quantity of lime required as flux; that depends both on the quality of the limestone itself, and on the nature of the iron ore. In a general way, where clay-band ironstone is smelted, from 12 to 17 cwt. of limestone will be necessary to each ton of pig-iron made.

The most advantageous plan would be, if possible, to use different ores, of such compositions as to flux themselves; but although this is seldom practicable, a great deal may often be done towards it by careful analysis of the ironstones available, and making judicious admixtures of them.

From 2 to 2½ tons of cinder are produced for one ton of metal; consequently it is obvious that if the cinder contain any considerable per centage of metal, the total loss of iron must be very serious, and strict attention is necessary so as to prevent any waste of metal from this cause.

CINDER.

The materials supplied to the blast furnace, after undergoing various chemical changes, are passed from it in the form of iron, slag or cinder, ashes, which form comparatively but a small proportion, and the gaseous products given off at the tunnel-head.

The slag or cinder, whenever a sufficient quantity has accumulated in the hearth, flows over the dam-stone at the cinder-notch, as a constant stream of liquid fire, and from its appearance gives an experienced keeper good indications of the state of the work of his furnace.

Cinder varies in its composition and appearance according to the materials employed in the furnace, but the following are its most usual appearances taken in connexion with the quality of iron produced.

The cinder, when a furnace is in good order and making No. 1 pig-iron, is, when cold, of a dirty white or cream or stone colour, and porous, its general appearance being somewhat like pumice-stone, but heavier, and is occasionally tinged with slight shades of colour. No. 2 and No. 3 iron are accompanied by a denser and more compact cinder than No. 1, but light in colour and well glazed on the surface. The cinder produced when forge-iron is made, has a close stony appearance, and is usually of a dirty yellowish-grey or pale-brown colour, with occasional tints of blue.

The cinder from white iron is dark-coloured, frequently black, compact when cold, and flows freely from the furnace, being very hot and liquid. The greenish-brown or "tawny" colour cinder is a very unfavourable one, and frequently is the precursor of a black cinder, the worst of all.

A large quantity of oxide of iron is usually present in a cinder much tinged with green.

The quantity of iron present in the cinder is very variable. At furnaces where suitable materials can be procured, and where they are judiciously worked, the loss of iron is small, the cinder not containing more than ½ to 1 per cent. of metal, but where furnaces are badly managed as much as from 5 to 15 per cent. of the iron is carried off in the cinder.

The above descriptions of the appearance of blast furnace cinder must be considered only as a general one, for in every district, and in fact at most works, some variation will be found in the composition, and consequently in the appearance of the cinder. The nature and quantity of the flux employed are of course the principal agents in effecting changes in the appearance and constitution of cinder, and this section must be considered as a continuation of the article on fluxes, and should be taken in connexion with that section.

The brown, green, and other dark shades or tints, in blast furnace cinders are caused by the presence of a large proportion of oxide of iron, which is consequently wasted by being carried away in the slag. This point is more particularly referred to in the section on smelting.

Glassy cinders may be considered as showing a deficiency of lime; and a cinder that instantly rises into a very light, porous, dirty-white or pale-brown mass upon water being thrown upon it whilst it is running from the cinder-notch, is usually considered a good cinder, and contains a considerable quantity of lime. Some consider that when a cinder "rises" upon cold water being thrown upon it, it is a sign that too much limestone is being used.

Cinder containing a large amount of oxide of iron usually retains its fluidity for a long time after passing from the stack, and such cinder in running into the beds or moulds made for its reception, continually finds its way *underneath* the slag already collected; whereas a good cinder, or one but little coloured, speedily cools and sets on leaving the stack, and as fresh quantities of hot slag flow from the furnace it runs *on the top* of the cinder already collected, making the surface uneven and very knotty, its colour being either pale yellow or yellowish-grey, shaded with tints of deep bright blue.

The cinder, in passing from the furnace, is run either into holes or moulds of suitable size made for its reception close to the furnace, and from which it is removed when sufficiently cooled; or it is collected in iron moulds or boxes with moveable sides, which are placed on a frame with wheels, and are drawn on a rail or tramway to the cinder-tip when sufficiently cold to allow of the sides of the mould or box being removed.

The large quantity of cinder produced in the iron-making districts has caused attention, at various times, to be directed to endeavours to turn it to useful account in the manufacture of pipes, roofing and paving tiles or slabs, and other purposes, as a substitute for stone, &c., but hitherto without sufficient success to be of any commercial advantage: indeed, the prospect of success of such a manufacture would not appear to be very great, when it is considered that but little demand for such manufactured articles would exist upon the spot, as abundance of excellent stone and clay are found in the iron-making localities, and the carriage of slabs, tiles, pipes, &c., to any considerable distance would be very costly; ornamental articles also would meet with a severe competition from established manufactures.

It is usually considered by those who take a favourable view of the manufacture of articles from blast furnace cinder, that they should have the material ready to hand, in vast quantities, and at a nominal cost. But it should be borne in mind, that the cinder is so constantly varying in its constitution and quality, that in practice, it would be necessary to re-work and reduce it to some regular standard of quality, or the results of the manufacture could never be depended upon; and the expense of doing this would greatly enhance the cost of the raw material.

FIRE-BRICK.

Abundance of clay, more or less suitable for making fire-brick, is usually found in the coal measures; in some situations it forms the floor or bed of all the veins of coal, however thin the coal may be, besides being found in other positions in the strata.

The fitness of a clay for making fire-brick may be known by subjecting a portion of it to the heat of a wind furnace. Pure silica and alumina, of which good fire-clay is composed, are infusible, or nearly so, but clays containing any appreciable quantity of alkaline earths, as lime, or magnesia, or metallic oxides, decompose when subjected to a high heat, and the various constituents fuse together; such clays are consequently unsuitable for the manufacture of fire-brick.

In making fire-brick it usually happens that sufficient attention is not paid to grinding the material fine enough to admit of its being so thoroughly mixed as to produce a brick of a nearly homogeneous substance; this point should not be overlooked, as the finer the material, the closer, and more even and solid will be the texture of the brick.

Sixty-four cubic feet, or about four tons of clay, will produce 1,000 bricks.

Varieties of refractory sandstone, plum-pudding stone, breccia, or conglomerate, are sometimes employed for forming the hearths and boshes of blast furnaces, and for other purposes where resistance to a high temperature is desired; but perhaps on the whole good fire-brick is as useful a material for the purpose as can be employed, and is now largely used both for the hearth and lining of blast furnaces, the bricks being moulded to the required size and form.

L

In some situations, in the millstone-grit series, are found what appears to be loosely re-aggregated masses of the disintegrated constituents of granite, consisting of quartz, and some felspar, in a whitish soft state, apparently similar to the China clay of Cornwall. This material, which consists almost entirely of silica, is crushed small by means of heavy iron rollers driven by steam or other power, and mixed with sufficient refractory argillaceous matter to allow of moulding, and after being sufficiently dried the bricks are exposed in a kiln to a very strong heat. These bricks, which resist intense heat, expand upon being subjected to a high temperature: they are largely used in various descriptions of furnaces.

ON THE UTILIZATION OF THE WASTE HEAT FROM BLAST FURNACES.

THE sheets of flame constantly pouring forth from the throat of a blast furnace in active operation show how large an amount of heat is passed into the atmosphere; and the endeavour to turn this waste heat to useful account has engaged a large share of attention, the result being the production of a variety of methods, more or less successful, for effecting the desired end.

The destruction of the fuel commences soon after it is put into the furnace, and long before anything like active combustion begins; a great portion of the volatile principles of the fuel being driven off by dry distillation and wasted, in the first stage of the smelting process, that of the materials becoming thoroughly heated: the products of the operations going on in the lower part of the furnace are also mingled with the foregoing, and though the vapours and gases given off at the tunnel-head of the furnace vary according to the nature of the fuel and other materials employed, they mainly consist of carbonic oxide, together with a greater or less proportion of hydrogen, carburetted hydrogen, carbonic acid, oxygen, nitrogen, carbon, bituminous matter, cyanogen, steam, &c. The properties of these gases have already been described under their several heads in the former part of this volume. As the whole of the above productions are not of an inflammable nature, and the carbonic oxide being carbon already half oxidized, although a large amount of caloric can be obtained by their use, a very high temperature is not produced by their combustion; this must be borne in mind in arranging the proportions of boilers and hot-blast pipes intended to be heated by means of these gases, as in order to obtain a given effect an increase of heating surface will be required over what is necessary when direct firing with coal is employed; although not nearly to the extent that has sometimes been stated, as may be seen by reference to the area of heating surface in a hot-blast stove heated by waste flame compared with direct firing, in the article on Blast—page 66.

Considerable difference of opinion exists as to the desirableness or otherwise of endeavouring to make an economical application of the waste heat at iron-works; the principal objections occasionally urged against the system being—the difficulty of making such arrangements as to give practically a useful effect, and the constant care and attention required to keep the apparatus in good working order;—the bad effect on the quality of the iron produced at furnaces where the gases are turned to economical account;—the increased difficulty of carrying on the operations of the furnace, and the irregular results in yield and quality of the iron;—and that in numerous instances in which the attempt to turn the gases to profitable account has been made, total failure has ensued, and capital, sometimes to a considerable amount, has consequently been uselessly expended.

We will now consider the foregoing objections; and as the points just recited, as well as some others not enumerated, have all in degree some relation to each other, in order to avoid unnecessary repetition, it will be as well to refer to them all in one general view of the whole subject, instead of taking each one separately. It is evident that the primary point is to plan the arrangements in the first instance in an efficient manner, and to do this and attain a successful result there are many points to which a proper consideration must be given. One of the methods adopted for the purpose of employing the waste gases is to insert a pipe of comparatively small diameter into the upper part of the furnace, and at an acute angle with it, for the purpose of bringing the gases down to the ovens or boilers: the throat of the furnace being open, the gases, owing both to their high temperature and the force of the blast, having a tendency to ascend, but a small supply of gas will find its way down through the tube in question, although the assistance of the draught of a lofty chimney in connexion with the ovens or boiler-flues may be employed.

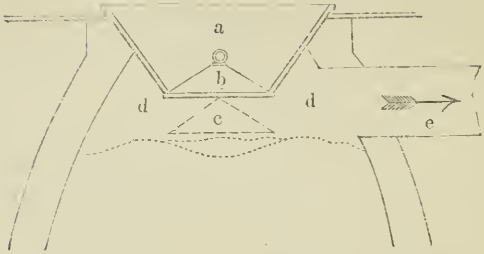
By wholly closing up the throat of the furnace so that no escape of gas takes place there, the whole of the gases produced may be passed through flues or other passages, and conducted to any desired spot, the force of the blast assisting to this end; but it is important that the gases be allowed to pass off as fast as produced, so as to avoid smothering combustion in the upper part of the furnace.

One great objection usually advanced against closing the top of a blast furnace is, that only white iron can then be made, the withdrawing the gas having a prejudicial though unexplained effect in deteriorating the quality of the iron.

It is true that in some cases closing the top of the furnace has appeared to produce very unfavourable results, but it by no means follows that such should necessarily be the case. Good iron can be made from a closed-top furnace by adopting proper arrangements. One very fruitful source of annoyance and irregularity of working of close-top furnaces is owing to the method of filling. The throat of a furnace is often closed by means of a cast-iron pan, in form of a hopper or funnel, the bottom or smaller end being closed by means of a cast-iron conical or bell-shaped stopper, suspended by a chain, which is attached to a lever and balance weight. The charge of mine, &c. is filled into the cast-iron pan, and the bell or stopper being lowered into the furnace when the material has worked down sufficiently, the contents of the hopper are allowed to fall down the inclined or conical sides of the bell into the stack, as shown in fig. 12, where—

a. is the cast-iron pan or hopper.
b. the bell closing the bottom of the pan.
c. the position of the bell when lowered.
d. the space in which the gases collect.
e. outlet by which the gases are conducted to the ovens or boilers.

Fig. 12.

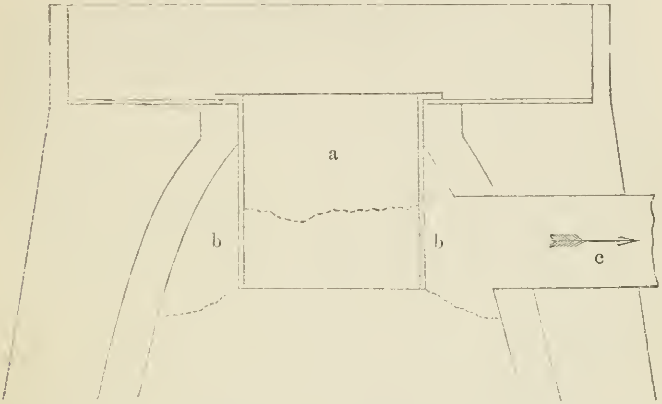


By this arrangement the furnace mouth is always closed, except only for the few moments during which the bell is lowered to admit a fresh charge to fall from the pan into the furnace.

There is one point of this arrangement that requires especial attention, and that is the angle of inclination given to the sides of the pan and bell: for if a steep inclination is used, the heavier part of the material will, in rolling down the sides of the pan and bell, attain a velocity sufficient to cause its falling close to the furnace lining, whereas the coke or lighter material will fall towards the centre of the furnace and thus cause unequal filling and distribution of the material, the effect of which will be the consumption of the fuel from the centre of the furnace, and the mine will then fall downwards or towards the centre in masses, and give rise to the bad work, scaffolding, white iron, and other effects complained of: a small inclination to the sides of the bell, say of about 30°, will remedy these evils. Probably some arrangement of gratings to be closed by means of plates to which a rotary or reciprocating motion could be given, so as to allow the materials, after being mixed, to fall perpendicularly and equally over the whole area of the furnace, would be found superior to the present pan and bell as just described.

Another method successfully adopted where a portion of the gases is required, is to insert an iron cylinder in the throat of the furnace, its depth being about equal to its diameter, leaving a cavity or recess between the lining of the furnace and the cylinder, in which cavity the gases collect—the cylinder being kept pretty well filled with material. This arrangement is shown in fig. 13, where a is the

Fig. 13.



cylinder, of ⅜ inch boiler-plate; b is the annular space in which the gases collect, and c the outlet by which they are conducted from the furnace.

In some instances, instead of employing the iron cylinder, an annular flue has been constructed in the masonry of the upper part of the furnace behind the lining, such flue having openings into the throat of the furnace.

Some portion of the gas escapes in this arrangement, but the filling can be carried on quite regularly: where it is considered desirable to employ the whole of the gas, it can be done quite successfully, without affecting the quality of the iron produced, by closing the top of the furnace, bearing in mind to attend to the points already adverted to.

Either of the three arrangements we have just noticed may, with proper care, be made to answer the intended end very well; the gases being brought down to the hot-air ovens or boilers, and a proper quantity of atmospheric air admitted, the gases are ignited either by being passed over a small fire maintained for the purpose, after which the combustion will continue until some interruption, such as casting, &c., causes the current or supply of gas to cease; or if a fire is not maintained for the purpose, it will be necessary after any interruption of the supply of gases, to ignite them again on the supply being again restored.

The flues, tubes, or channels, through which the gases are passed should be sufficiently roomy for their rapid conduction, and sharp angles or bends should be carefully avoided. The gases being highly explosive when mixed with a proportion of air, it is necessary to make proper provision to prevent accidents from this cause. This may be most conveniently effected by providing large valves or doors in connexion with the gas conductors, such valves to be slightly closed so as just to prevent escape of gas, but in such a way as to present little or no obstacle in the event of an explosion.

These valves or doors should be so constructed and placed as to close of themselves after the force of an explosion is expended, or continual care will be required in closing them, as explosions are of frequent occurrence, and, unless ample vent is provided, their effects would often be of a very disastrous character.

But perhaps on the whole the best arrangement for economizing the waste gases and heat from the blast furnace, is to construct the hot-air ovens or boiler-flues at as near a level as possible with the upper part of the furnace, and make a roomy and as direct a communication as can conveniently be obtained between the ovens and boilers and the furnace, a few feet below the level of the filling-place, and thus take the flame immediately to the point where its effect is required; the top of the furnace being left open, but kept well charged with material. It will be as well to have no tunnel-head or chimney to the furnace-throat, as a high tunnel-head will have some effect in causing the flame to rise above the filling-place, and thus prevent so large a supply passing to the ovens and boilers. There is no need in using this method to provide any means of kindling the gas, or for admitting atmospheric air, as sufficient air will be supplied from the tunnel-head to maintain active combustion.

In adopting either this or any other arrangement, it will be well to avoid small or tortuous flues and passages; indeed, under the boilers, a large open space will be more favourable to the mixing of the air, flame, and gases, and consequently to thorough combustion, than any other arrangement. The same remarks apply to the hot-air ovens, care being taken, by means of proper fire-brick stoppings, to cause the heat to play equally over the hot-blast pipes, instead of at once passing to the flue communicating with the chimney-shaft. Roomy flues and connexions with the stack are necessary, as a large quantity of hot air, gas, and flame, are required to be passed through the flues at a small velocity. Considerable loss of useful effect takes place in passing heated air and inflamed gases along flues at great velocity, as they are hurried to the chimney before having had sufficient time to transmit their caloric to the boiler or other apparatus they are intended to heat. Contracting the area of air and smoke passage increases the velocity, and friction increases as the square of the velocity; thus, if we call the friction of a column of air moving at a velocity of 10, as being equal to 4, and then contract the area of passage so as to double the velocity or make it equal to 20, the friction will then be 16. The proportions of chimneys also require great attention, a common error being making them of too small sectional area; or supposing the area at the bottom to be sufficient, instead of their being carried up of equal diameter or area, they are frequently "throttled," or so much contracted in their upper portion as seriously to interfere with their proper action.

Varieties of these arrangements have now been in use for years at different iron-works with complete success; the results being saving in fuel and labour and great regularity in action; well-constructed apparatus requiring no further attention than the occasional clearing the pipes, &c., of the dust that accumulates.

The advantages obtained by turning to useful account as much as possible of the waste heat from the furnace, are very considerable: not only is a large saving of fuel effected, but, what is of more importance, labour is also economised, and moreover the regularity and degree of heat obtained from the gases is well suited for raising steam and heating the blast without unnecessarily burning out either the boilers or hot-air pipes; and when once the apparatus is in working order a very small amount of supervision is sufficient to maintain its proper action. At the same time there can be no doubt that some qualities of fuel and some methods of detail in furnace arrangements are more or less favourable to the satisfactory working of the system than others.

Taking the gases from a point too low down in the furnace would be likely to cause great disturbance to the smelting operations, by preventing the action of a proper degree of heat and deoxidation on the material in the upper part of the furnace: and in one case, mentioned to the writer as an instance in which the system had failed, although thoroughly carried out, it was stated that, the gases had been so completely withdrawn, that it was possible for a person to cross over the materials in the furnace, at the filling-place, without risk of being scorched; this very fact being quite sufficient explanation of the cause of failure.

By proper attention to the points necessary to be taken into consideration, the waste heat and gases from puddling and mill furnaces, may be advantageously employed in raising the steam for the forge and mill engines. The application of the system to puddling and other furnaces has not received the attention the importance of the subject demands, and although in some instances considerable difficulty was encountered in first bringing the method to a successful issue, no obstacle but such as may be overcome by judicious arrangements, to meet the requirements of each particular case, need prevent its general application.

WROUGHT IRON.

THE manufacture of wrought or malleable iron direct from the ore, has already been adverted to. This method is not at the present time employed at all in Britain, all iron being first procured from the ore in the form of fusible carburet of iron, and the conversion of this carburet into soft or wrought iron is what we have now to consider.

Carburet of iron is a combination or admixture of iron with carbon in the form of cast-iron, and wrought-iron is the de-carburetted cast-iron. Wrought-iron differs from cast-iron in its mechanical structure and in containing less impurities. The greater the amount of carbon that iron contains the more fusible is the metal; as the quantity of carbon is lessened the more infusible the iron becomes, and after the carbon is expelled from the iron it no longer melts on being subjected to a white heat, but becomes soft and pasty, and the particles of metal adhere together, allowing of the malleable iron being shaped into any required form, and also giving rise to the remarkable property of welding, by which pieces of malleable iron may be joined to each other at a high temperature.

The process of de-carbonizing the pig or cast iron varies somewhat according to circumstances, in some cases being partly carried on at a "refinery" and completed at the "puddling-furnace," and sometimes being conducted wholly at the puddling-furnace, without the intervention of the finery process, by the process termed "boiling."

The "finery" or "run-out fire" consists of a shallow coke fire blown with blast, the fire being surrounded with iron troughs or boshes, filled with water to prevent their melting, the bottom of the hearth being sand; and the blast tuyeres dip down towards the surface of the metal so as to expose it to the oxidizing influence of the blast.

The use of the refinery is to assist in de-carburetting the pig-iron, and of thus saving labour in the puddling-furnace, and it is also used as a means of improving the quality of pig-iron, which it effects to a small degree, but it is a rough and wasteful method of manipulation. After the pig-iron is melted it is run into a chill mould or cast-iron bed, which is kept cool by a current of water; it is then called "refined plate."

Refined plate is very hard and brittle; its fracture has a metallic white colour, and a somewhat striated crystalline but not granular appearance; it is usually run into a cake or plate about 1½ or 2 inches in thickness.

About 22½ cwts. of pig-iron and 6 cwts. of coke are required for the production of one ton of refined metal, from 10 to 12 per cent. of metal being lost by oxidation, and a large quantity of cinder or slag being formed. The process of refining may be considered as really costing, including loss of metal, 13s. per ton when the pig-iron is of the value of 60s. per ton; but in comparing the expense of the two processes of making malleable iron, i. e., by means of the refinery, or by means of boiling grey pig, it is necessary to bear in mind the lesser cost of puddling refined metal, and consequently the cost of refining must be considered as equal to a loss per ton, including coke and labour, of 10s., taking the price of pig-iron at £3 per ton, or a loss of 12s. 6d. per ton on the malleable iron. The finery process is expensive, and may be considered to effect but a small improvement in the quality of iron, more especially when the pig-iron is of a very indifferent description.

The refined metal is next subjected to the operation of puddling, which is performed in a reverberatory furnace, the method of procedure being as follows :—When the furnace is sufficiently heated by the flame of the ignited fuel in the grate, the refined metal, in quantities of about 3 or 4 cwts., is placed in the hearth and becomes thoroughly softened in the course of twenty or thirty minutes; when softened and friable the heat of the furnace is lowered by partly closing the damper, and the mass is thoroughly stirred, small quantities of hammer or roll scales, or other magnetic oxide, being added, also water occasionally; the use of the water and oxide of iron being to cause a combination of the oxygen they contain with the carbon of the iron. The metal swells up or ferments through the escape of the carbon, which is volatilized or converted into carbonic oxide, and which burns with a blue flame. The stirring of the metal is continued, and as the iron becomes de-carbonized, the evolution of gas and the consequent fermentation cease, and the iron becomes "dry," or is reduced to a loose granular or sandy state: this takes place in about forty or fifty minutes from the time the refined metal was put into the heated furnace. When the metal has been sufficiently manipulated, the chimney damper is raised, the draught through the furnace restored, and with the increase of temperature the particles of metal begin to adhere together, and the mass "works heavy." The iron is now formed into lumps or "balls," and when the whole contents of the furnace are formed into irregular-shaped masses of 60 or 70 lbs. weight, the furnace door is closed for a few minutes and the balls subjected to a welding heat. They are then withdrawn, one at a time, and subjected to the action of a hammer or squeezer, and while still hot are rolled into rough bars, such bars being denominated "puddled bar," or "No. 1 mill-bar." The whole operation will require from 1½ hour to 2 hours, according to the quality of the iron and fuel, skill of the workman, &c. Seven heats, of 3½ cwt. each, may be procured in a turn of 12 hours.

When the operation of "boiling" is the method used for converting cast into wrought iron, the pig to be employed is grey to a greater or less degree; whereas in the puddling process refined metal or white pig-iron is used. The furnace employed for boiling is similar to that employed for puddling refined metal, with the exception that a puddling furnace need be only about 7 or 8 inches deep, whereas the boiling furnace requires to be 10 or 11 inches in depth, for the grey iron containing a much larger proportion of carbon than the refined metal, it is much more fluid when melted, and ferments or rises much more than white pig or refined metal does. A larger quantity of cinder is also necessary in boiling than in puddling. The difference in the amount of carbon the iron contains, and its consequent fusibility, and in the time required for the crystallization or coagulation of the metal, causes the difference between puddling and boiling, although the two processes are in the main nearly similar. When a charge of metal has been withdrawn from the boiling furnace, a portion of the fluid cinder in the hearth of the furnace is tapped off at an aperture under the working door; as soon as this is done, some cinder from the hammer and rolls, or raw hematite, or other iron ore very much calcined, is put around the inside of the furnace to protect the boshes: the grey pig is now charged, and when melted is incorporated with the cinder. This part of the process requires about three quarters of an hour from the time of charging; in another twenty minutes the iron begins to rise, and boils for about fifteen minutes, during which time constant stirring is required, additions of hammer-scales, water, &c., being made as in the puddling process. When the boiling ceases, the cinder which has been floating on the top of the iron subsides, the particles of iron begin to adhere, and the metal is now worked up and balled as in puddling. Five or six heats can be worked in a turn of 12 hours.

Fig. 14 is a section of a puddling furnace, as arranged for the boiling process, and Fig. 15 is a plan of the same—the scale being five feet to the inch.

a. is the grate, in which bituminous coal is burned.

b. the hearth or body of the furnace, the bottom of which is formed of one or more thick cast-iron plates, supported on strong iron bearers. The sides are also formed of cast-iron plates, which, as well as the bottom plates, are protected from the action of the fire by the cinder, and by a supply of hematite or other iron ore.

c. the flue, which, as well as the other brickwork of the furnace, is constructed of fire-brick

Fig. 14.

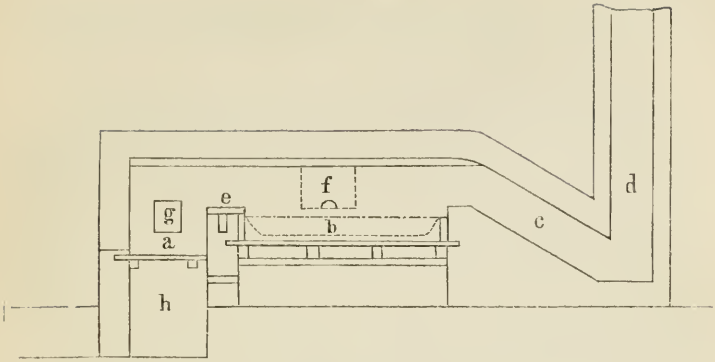
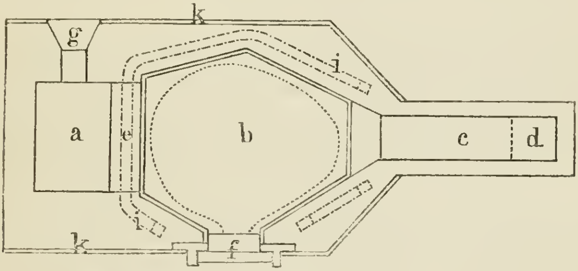


Fig. 15



d. the chimney, usually about 25 feet in height, and provided at the top with a damper, by means of which the draught, and consequently the heat of the furnace, may be regulated. The chimney (with the exception of from six or eight feet at its base), is usually carried upon a cast-iron plate or bearer, supported on columns of iron or brickwork, to prevent the necessity of removing the whole stack when the bottom portion is burned out, which frequently happens although the upper portion is uninjured. The outer brickwork of the upper part of the stack is usually of common brick, well secured with iron ties.

e. a low wall of fire-brick, called the "bridge," which separates the fuel in the grate from the iron and cinder in the body of the furnace. The flame of the coal in the grate a. rises against the fire-brick arched roof of the furnace, and is then reverberated or thrown back upon the iron, &c., in the hearth b.

f. is the door at which the iron, &c., is introduced into the furnace. In the lower part of this door is a small aperture, which can be closed at pleasure, and it is through this small opening that the greater part of the manipulation is carried on by the workman, who is termed a "puddler." The door is opened by raising it, which can be expeditiously effected, as the door runs in a frame or guides, and is balanced by a weight. Below this door is the tap-hole or aperture at which any superfluous cinder is run off.

g. is the aperture by which the coal is supplied to the grate, and at which the fuel is raked evenly over the area of the grate-bars.

h. the ash-pit, which should be sufficiently roomy to allow of a good supply of air to the grate-bars, and of opportunity for clearing the bars from clinkers. An opening is sometimes left between the ash-pit and the space under the hearth b., to allow of the admission of air so as to assist in keeping the iron bottom cool.

i. channels left for the passage of air to aid in keeping the side-plates cool. The bridge e is also made hollow to the same end. In some cases cast-iron troughs or boshes are employed, through which a flow of water is maintained.

k. the brickwork of these furnaces requires to be strengthened by cast-iron binder plates, about 1¼ inch in thickness, and fully the height of the furnace. The plates on the opposite sides of the furnaces are held together by stout wrought-iron bolts.

The older description of puddling furnaces had fire-brick or sand bottoms, but iron bottoms are now generally used.

A good deal of difference in practice exists at different works as to boiling and puddling. Refining and puddling are mostly carried on where the blast furnaces are driven hard, and much more attention paid to producing a large yield of inferior iron than superior quality. The use of refined metal also enables the puddler to turn out a larger yield every 12 hours than he could do by boiling grey pig, and the puddling also effects saving in fuel; though on the other hand the coke used for refining must be taken into account.

It is a well-known fact that the more rapidly iron is produced the more its quality is deteriorated; and this remark applies equally and as truly to the operations at the puddling or boiling furnace as to the smelting, and where the pig-iron is of such a quality as to keep liquid while the work goes on slowly good results will be obtained. Granular iron is caused by too quick work in the puddling process, for if the workman forms the iron into balls, the moment the particles will commence adhering together, or before it has fully "come to nature," the fracture will be crystalline, and such iron will require a large amount of subsequent heating and rolling thin, before it will become fibrous. Iron not well melted, or which crystallizes very rapidly, will produce granular iron.

Good grey pig must be the material employed when good malleable iron is required: for although by the use of white pig-iron the labour of puddling is lessened, and consequently each puddling furnace is enabled to produce a larger make, and with a smaller proportion of fuel, than when grey iron is operated upon, still this gain is made at the expense of the malleable iron procured, which is never of good quality when made from white pig-iron alone. Mixtures of white and grey pig and refined metal may produce a good quality of malleable iron, but not without using a fair proportion of sound grey iron. It is an excellent plan, where good iron is required, to make up the charge for the boiling furnace of a variety of qualities of good pig-iron.

No subsequent piling, re-heating, and rolling, will improve the quality of the poor, rough, dirty, harsh, rotten material, that is made at some works as malleable iron. The pig-iron from which it is made is frequently exceedingly bad, in consequence of want of care or judgment in smelting, and the management at the puddling furnace such, as precludes advantage being taken of the opportunity of improvement the puddling permits.

Merchant iron should be malleable and weld well, and should be manufactured from good grey pig. Fine fibrous iron must be made from fusible pig-iron, and be thoroughly manipulated whilst in a fused state, and not be put together too hastily; either fibrous or granular iron may be produced from the same pig-iron by difference in working.

Granular iron is harder when cold than fibrous iron, and railway bars answer better when made from refined metal than if made of boiled grey pig, as hardness is desirable for rails: at the same time the degree of hardness may be excessive, as no rails should be brittle nor approaching to it, but the great competition in the manufacture of rails frequently reduces the price so low, especially in times when but a small amount of business is doing, that a large quantity of very inferior quality are produced: and whilst so much attention is given to procuring rails at the lowest possible figure, it is not surprising that their quality should be very indifferent. Rails are consequently manufactured from very crude iron, a strip of better quality of iron being usually given to the top and bottom surfaces than to the interior; but in many cases they would be correctly described as consisting of bad iron at top and bottom, and worse inside. The mill-bars from which the piles for rails are formed, are frequently so rough and dirty, covered with scales of black oxide and earthy impurities, and the rage for economy rendering it necessary to pile a very poor quality of No. 1 mill-bar between the comparatively good, or No. 2 iron of the exterior top and bottom, and in some cases side, pieces, so as to prevent any portion of the interior from working out to the exterior of the rail, it follows that not only is the outside of the rail imperfectly welded to the interior portion, but the various bars both of the No. 1 and No. 2 portion are not properly united to each other, and the rail, instead of being homogeneous, is made up of thin independent layers of iron, which layers of course separate when exposed to weight and concussion—being the cause of the lamination of rails so much complained of. Dirty iron will not make a sound weld, and in all cases where dirty crude iron is enclosed by other iron of ever so good quality, the cinder, scales, &c., cannot escape, and consequently the various portions of the pack never become thoroughly consolidated and welded together.

The interior portion of rails is commonly made of No. 1 mill-bar, that is, iron direct from the puddling-furnace, rolled while still hot into rough bars; the iron supplied to the puddling furnace being mostly poor refined plate, or sometimes consisting of a large proportion of white pig. The tops and bottoms of the blooms are formed of No. 2 mill-bar, which is No. 1 or puddled bar sheared into lengths, the pieces being piled upon each other, subjected to a welding heat, and again rolled into bar: this No. 2 bar being thus condensed, and a portion of the cinder being squeezed out from it.

The fracture of a common rail may present no very apparent want of solidity and uniformity in texture, but this is frequently owing to the difficulty of tracing irregularities in a bright crystalline fracture. If the fracture is filed smooth or "got up," the lines of the different bars in the packs will frequently be distinctly seen, and the application of dilute acid will assist in their development, showing also where any deficiency in the welding exists through the presence of dirt, scales of oxide, &c.

The balls from the puddling or boiling furnace are, as soon as taken from the furnace, placed under the hammer, and after being condensed are rolled into bars called No. 1 mill-bar. The operation of hammering is termed "shingling," and the rolls at which this rough bar is made are termed "forge rolls." In some cases the use of the hammer is dispensed with, and the balls from the puddling furnace are placed under a "squeezer," consisting of a pair of strong cast-iron jaws, the upper one being moved by a lever driven by power; by this means the mass of iron is somewhat condensed and a part of the cinder squeezed out, before being passed to the rolls; but the effect of the squeezer in expelling the cinder is far below that obtained by shingling under the hammer. The squeezer is generally employed where common iron is worked, but when a good quality of iron is required, thorough shingling is necessary. There is also an incidental advantage in using the hammer, and that is, it breaks up and scatters any ball of iron that has not been well puddled and put together, discovering the want of skill or care of the puddler: whereas the squeezer presses the particles of metal and cinder together, causing them to adhere in a mass, frequently only just sufficient to pass through the operation of rolling, and on this account is sometimes termed the "puddlers' friend."

Where a first-rate quality of iron is required, the balls from the puddling furnace are placed under the hammer, and shingled down into rough plates or slabs, about $\frac{5}{8}$ or $\frac{3}{4}$

inch in thickness, and when cold these plates are broken in pieces, piled and re-heated and rolled into bars. None but good iron, well puddled, would stand such shingling, and the iron is both well condensed and has the cinder thoroughly worked out of it, by such manipulation. The pieces of such rough plates or slabs when broken up for piling and re-heating, are termed "stampings."

The fracture of good puddled bar, or stampings, presents a brilliant crystalline appearance, free from dirt and cinder, and the crystals small and regular, with very little or no appearance of fibre. The exterior is rough, with scales of oxide adhering, and the edges of the bars, instead of being sharp and square, are usually ill-formed and cracked. In some cases where very clean iron is required, as, for instance, in the manufacture of tin-plate, the No. 1 or No. 2 bars are immersed in water immediately upon their leaving the rolls, for the purpose of detaching the scales of oxide adhering to them.

The No. 1 mill-bar being sheared into lengths, the pieces are placed or "piled" upon each other and subjected to a welding heat in the "balling" or re-heating, or, as it is frequently termed, the "mill-furnace;" this is a reverberatory furnace, somewhat like a puddling furnace, but having the hearth arranged in a different way. The accompanying plan and section, Figs. 16 and 17, will explain the construction of a mill or ball furnace, the scale being five feet to the inch.

FIG. 16.

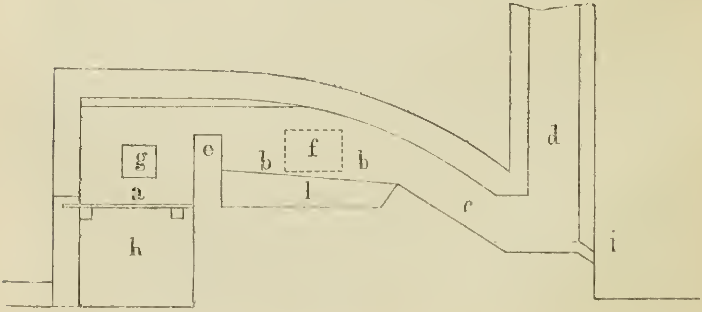
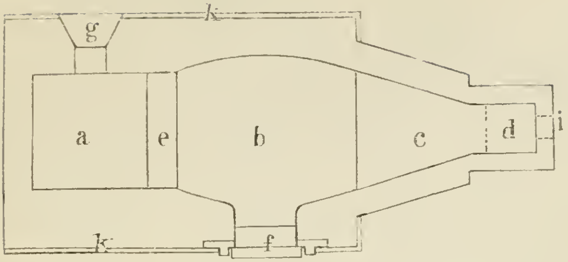


Fig. 17.



a. the grate, the area of which is required to be considerably larger in proportion to the area of the hearth than in the puddling furnace; a very high temperature being necessary in a re-heating furnace.
b. the hearth, which is formed of silicious sand. The hearth may either be supported on a cast-iron plate, or on brick arches, or be filled in solid. A steep slope towards the flue should be given to the sand bed so as to allow of the slag that forms when the furnace is in use to pass off quickly.
c. the flue.
d. the chimney, which is constructed in a similar manner to that of a puddling furnace chimney.
e. the bridge, preventing the fuel and iron from coming in contact.
f. the door at which the piles of iron are introduced into, and withdrawn from, the furnace. A small sight-hole, closed with a moveable stopper, is provided in the door, to allow of the action of the furnace being watched without the necessity of opening the door and thus cooling the furnace.
g. aperture at which the grate is supplied with fuel.
h. the ash-pit.
i. the floss-hole, at which the cinder or silicate of iron escapes from the furnace, after passing over the inclined bed of the furnace and flue. A small fire is kept burning at i. on the exterior of the furnace, for the purpose of maintaining the slag in a fluid state, so that it may pass off as fast as it collects and not choke the lower part of the flue.
k. exterior binder-plates, similar to those of a puddling furnace.
l. the sand bed of the hearth.

The pile, when sufficiently heated, is withdrawn from the furnace, and passed first through two or three grooves in the "roughing-rolls," and is finally formed into a bar of the required form and dimensions, by being passed through two or more grooves in the "finishing-rolls." As soon as the right form and size are attained, the ends of the bars are cut off even by means of circular steel saws, revolving at a high velocity, with nearly one-half of their diameter immersed in water, the bar to be cut being pushed up to the teeth of the saws by a sliding carriage. After the ends are cut off, the bar is straightened on a cast-iron bed by means of wooden mallets.

Where bars of a superior quality are required, the pile of No. 1 mill-bar, instead of being at once rolled into finished iron, is again rolled into a bar called No. 2 mill-bar; and this No. 2 bar being again sheared into lengths, piled, and re-heated, is rolled into a finished bar.

Small bars are not rolled from "piles" but from "billets," which are pieces of No. 1 mill-bar of such size and length as will, upon being re-heated and rolled ont, form a bar of the size and length required.

Boiler-plate is rolled from slabs well worked and formed under the hammer; the boiler-plate rolls doing nothing more than reducing the slab in thickness and extending it into a plate of a given size. Sheet-iron is rolled from lengths of flat mill-bar.

Neither sheet-iron nor boiler-plate require a welding heat in rolling, and they are therefore not heated in the mill-furnace used for re-heating piles of mill-bars, but in a furnace or oven, constructed on the reverberatory principle, but with a weak draft and small area of grate, as not more than a cherry-red heat is required.

The pig-irons generally employed for making malleable iron are No. 4, mottled, and white, as these descriptions contain the smallest amount of carbon, and are consequently puddled quicker and with less expense for labour and coal than iron containing a greater amount of carbon. There is no objection to the use of the greyest and most fluid pig for the purpose of making malleable iron, except that the operation of boiling will require more time, and also more coal and labour, than boiling iron containing less carbon, or puddling white iron; and the malleable iron resulting from boiling very grey iron will be of excellent quality. The length of time that grey iron remains fluid in the boiling furnace is highly favourable to its being properly worked, and to its crystallizing slowly and regularly, and consequently forming a clean, strong, and fibrous iron.

The benefit to be obtained from the employment of artificial fluxes in the puddling furnace has sometimes been strongly insisted on. The materials that have been tried are caustic soda, caustic potash, common salt (chloride of sodium), lime, white clay, &c., either separately or mixed in various proportions, or to some extent chemically combined. There can be no doubt but that by the addition of suitable ingredients the properties of the cinder in the boiling furnace may be considerably varied, and to a greater or less extent be made to combine more readily and completely with the impurities of the pig-iron than would be the case without the addition of such flux; but the continual variations in the quality of the pig-iron, and consequently of the cinder, would require so much care and attention to ascertain its properties and the necessary addition of flux, that practically, the use of such fluxes may be considered as possessing but little value.

The following summary will afford a good idea of the proportions of material and cost of labour, in producing bar-iron from pig-iron by the refinery, and also by the boiling process:—

REFINED METAL.

22¼ to 22½ cwts. grey forge pig-iron, at 60s. per ton,	£3	7	6
6 to 7½ cwts. coke, say	0	4	6
Wages—refining, 1s., breaking metal, weighing, &c., 6d.,	0	1	6
Blast, power, &c., ...	0	1	0
Cost of a ton of refined metal, .	£3	14	6

NO. 1 MILL-BAR.

21¼ to 21½ cwts. refined metal, at 74s. 6d. per ton,	£4	0	0
Wages—puddling, 6s. 6d. to 7s. 6d., . .	0	7	0
Coal, 16 to 18 cwts., ...	0	5	0
Wages—shingling, 1s. 6d., rolling, 1s. 2d., .	0	2	8
Power and machinery, ...	0	3	0
Labour, weighing and breaking metal, removing ashes, &c.,	0	0	10
Cost of a ton of puddled bar, .	£4	18	6

FINISHED BAR.

21½ cwts. of No. 1 mill-bar, at 98s. 6d. per ton, .	£5	5	11
Wages—shearing and piling, 9d., heating, 3s., rolling, 4s. 6d., cropping, straightening, and weighing, 1s.,	0	9	3
Coal, 10 to 12 cwts., ...	0	2	6
Power and machinery, ...	0	2	0
Labourers, ...	0	0	8
Cost of a ton of finished bar, .	£6	0	4

Requiring from 23·64 to 24·187 cwts. of pig-iron to a ton of No. 1 mill-bar, or from 25·41 to 26 cwts. of pig-iron to a ton of finished bar.

BOILING GREY PIG-IRON.

22¼ cwts. grey forge pig-iron, at 60s. per ton, .	£3	6	9
Wages—puddling, from 8s. 6d. to 10s. 6d., .	0	9	6
Coal, 20 cwts., ...	0	6	0
Wages—shingling and rolling, . . .	0	2	8
Power and machinery, ...	0	3	0
Labour, weighing and breaking metal, removing ashes, &c.,	0	0	10
Cost of a ton of No. 1 mill-bar, .	£4	8	9

FINISHED BAR.

21½ cwts. No. 1 mill-bar, at 88s. 9d. per ton, .	£4	15	5
Wages—heating, rolling, &c., . . .	0	9	3
Coal, 10 to 12 cwts., ...	0	2	6
Power and machinery, ...	0	2	0
Labourers, ...	0	0	8
Cost of a ton of finished bar, .	£5	9	10

Requiring 22·25 cwts. of pig-iron to a ton of puddled bar, or 23·91 cwts. of pig-iron to a ton of finished bar.

If pig-iron, worth 70s. per ton, be converted into puddled bar by boiling, without the intervention of the refinery process, the No. 1 mill-bar will cost about the same as if it had been made from pig-iron worth only 60s. per ton, and subjected to both refining and puddling.

RAILS.

26½ to 27 cwts. pig-iron, at 60s. per ton, . .	£4	1	0
Coal, 40 to 45 cwts. at 6s. per ton, . .	0	13	6
Labour at refinery, ...	0	1	8

	£	s.	d.
Labour, puddling and shingling, . . .	0	9	0
Ditto heating, rolling, sawing ends, straightening, weighing, &c., ...	0	7	0
Power and machinery, say, . . .	0	5	0
Cost of a ton of railway bars, .	£5	17	2

22½ cwt. of puddled-bar to a ton of rails, including a piece of No. 2 iron at top and bottom.

Good bar-iron is usually considered to sell at a fair remunerating price when it fetches double the cost of the pig-iron from which it is manufactured; thus, if pig-iron is worth £3 per ton, bar-iron should be worth £6, and No. 1 mill-bar £4 15s. to £4 17s. 6d. per ton.

Pig-iron is sometimes sold at a certain agreed rate in the £ on the price of bar-iron, at the time of delivery; for instance, 8s. 6d. in the £ for white pig-iron, i. e., bars being worth £7—the price of the pig-iron would be £2 19s. 6d.

Rails are usually from 5s. to 7s. 6d. per ton higher in price than bars. Heavy angle and T iron is usually 20s. per ton, and light angle and T iron from 30s. to 40s. per ton, above the price of bars. Sheet and hoop iron 30s. to 40s. higher than bars.

The description of machinery employed for rolling malleable iron is shown by the accompanying sketches; Fig. 18 being the elevation, Fig. 19 the plan, and Fig. 20 the end view of a train (or two pairs) of 18-inch chilled boiler-plate rolls; the scale being five feet to the inch.

a. the roughing-down rolls.
b. the finishing rolls.
c. the point at which the engine-power is applied for driving the mill.
d. a pair of toothed wheels called the driving pinions, by means of which the motion given to the lower rolls by the engine is communicated to the upper rolls.
e. coupling-boxes which connect the coupling-spindles with the rolls, and which coupling-boxes are moveable at pleasure.
f. the coupling-spindles.
g. the standards in which the rolls work, usually termed housings.
h. cast-iron bed-plate, which requires to be very strongly secured to masonry below the floor.
i. the screws by means of which the upper rolls may be raised and lowered, so as to give any required space or gauge between the upper

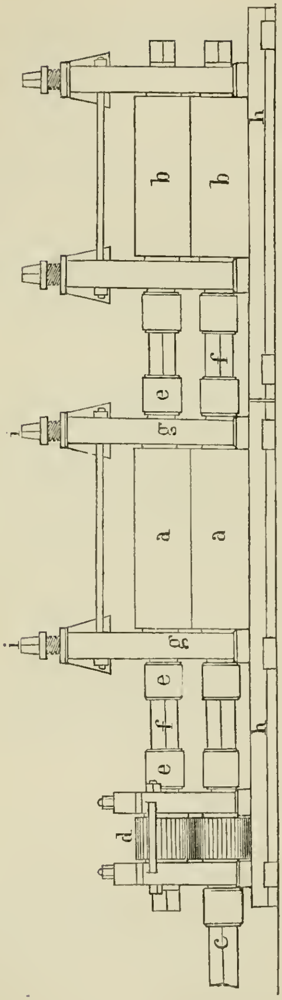


Fig. 18.

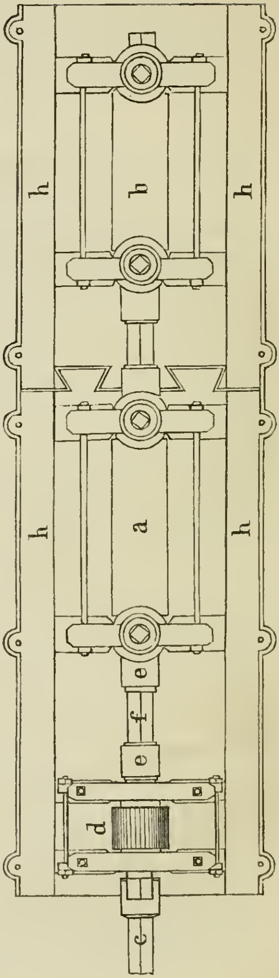
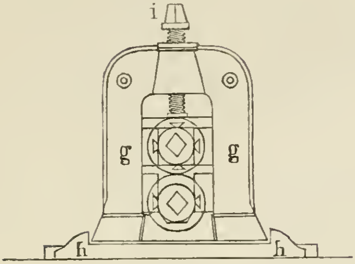


Fig. 19.

and lower rolls, thus regulating the thickness of the plate or sheet of iron produced. When at work, these screws are furnished with handles conveniently within reach of the workman, so that the distance between the rolls may be altered with the greatest facility and nicety.

Fig. 20.



In the above "train of rolls" or "boiler-plate mill," the cylinders or rolls are perfectly true and smooth, and they are frequently "chilled," or surface-hardened, by being cast in iron moulds, (which process is to be more fully described hereafter,) and are then turned in a lathe with the utmost accuracy, the object being in this case to produce sheets or plates of iron of an even thickness and having a smooth surface. In rolling bar-iron, whether round, square, or flat; rails, angle and T iron, or any other form, the rolls, instead of being smooth cylinders, have grooves turned in them of the form and size of the iron required, and the heated iron being forcibly drawn between the rolls, (which are driven at a high speed,) it takes the shape of the grooves through which it has been passed.

The rolls are of very varying size and form according to the purpose for which they may be intended: thus, the first train (or two pairs) of rolls through which the iron is passed after leaving the shingling-hammer or squeezer is called the "forge train," and at them the puddled bar or No. 1 mill-bar and billets are formed. The forge rolls are usually 16 or 18 inches diameter, and 4 feet to 5 feet 6 inches long, one pair of the rolls being furnished with grooves suitable for producing billets and small flat bars, and the other pair for rolling flat bars, five, six, or more inches wide.

The next set of rolls, in making bar-iron, consists of a train called "the bar mill:" they vary from 8 to 16 inches in diameter, and the first pair or "roughing-down rolls" at which the billets or piles are drawn approximately to the desired form, are usually from 2 feet 6 inches to 5 feet in length. The next pair of rolls of the train are called "the finishing rolls," and they vary from 2 feet to 3 feet in length, and at these rolls the bar is finished to the exact size required.

Rails are made at a train of rolls having grooves turned in them of the section or form required.

Very small iron, as rods, &c., which require to be rolled quickly on account of their cooling so rapidly, are made at a mill consisting of *three rollers* placed one above the other, and containing the necessary grooves, instead of only *two rollers* as in boiler-plate and bar mills. This arrangement with three rollers allows of course of two feeding-places, and the rod, when once passed through, say, for instance, the lower range of grooves, is not lifted back and again fed in from the same side as before (as in the bar mill), but the rod, when passed through between the *bottom* and middle rolls, is returned through one of the grooves between the middle and *top* rolls, thus much expediting the operation of rolling. The rolls of the rod or small iron mill are also driven at a high velocity.

The dimensions and arrangements of the rolls vary at different works, and also according to the description of iron made. In some cases roughing down and finishing grooves, or squares, round grooves, or flat and square grooves, being turned on the same rolls, &c. The rolls requiring the greatest amount of power to drive them are the sheet and boiler-plate mills.

An engine of 20 horse-power is capable of driving an 8-inch train of bar-iron rolls, a saw for cutting off the ragged ends of bars while hot, and a lathe for turning rolls.

A 60-horse engine will drive a shingling-hammer, a train of forge rolls, and a train of 16-inch roughing down and finishing rolls for bar-iron.

An engine of 100 horse-power will drive a shingling-hammer, train of forge rolls, a 20-inch train of boiler-plate rolls, and a rail mill.

The great labour, cost of fuel, and necessity of powerful machinery in the prosecution of the processes now in use for converting cast into malleable or wrought iron, has induced a vast number of persons, more or less competent for the task, to endeavour to suggest other methods of more readily decarbonizing the pig-iron and saving labour and fuel in the production of wrought iron; the result being the securing almost numberless patents for supposed improvements, scarcely one of which patented processes have been of any benefit to the inventors, or have any practical or commercial value.

Amongst the various methods that have been suggested for the more facile production of malleable iron, may be mentioned, passing a blast of dry steam through the molten pig-iron in the puddling furnace; forcing a blast of both air and steam into the puddling furnace; also various commercially valueless methods of obtaining malleable iron direct from the ore, &c., &c.; but the most recent attempt at a new system of making wrought iron, and one that has caused an extraordinary amount of unnecessary alarm and excitement amongst iron manufacturers and other branches of trade, is the process known as "Bessemer's Patent," and which being made public at the last meeting of the British Association for the advancement of Science, held at Cheltenham, caused a large share of attention to be immediately directed to the subject. The following are the claims made by the patentee under his first two patents:—

"Letters Patent to Henry Bessemer, of Queen Street Place, New Cannon Street, in the City of London, for improvements in the manufacture of iron and steel. Patent dated January 4th, 1856.

"Now the object of my present invention is the more perfect and complete refinement of the iron, whereby it gradually loses the properties common to pig or crude iron, and acquires the properties of cast steel, or of pure or decarbonized iron, while it still preserves such a state of fluidity as will admit of its being cast into ingots or other desired forms or articles by the process of founding. For which purpose I expose the iron in a more divided or extended form to the intense heat of the furnace or furnaces hereinafter described, and to the oxidizing action of a blast of air, by keeping such fluid metal in motion and continually bringing fresh portions of it in contact with oxygen and with the intensely ignited fuel, or with the highly heated interior surface of the furnace, the metal being thus kept in a fluid state until the desired amount of decarbonization or refinement is arrived at.

"The iron to be used for the purposes of my present invention may be conveyed by a gutter in a fluid state direct from the smelting furnace, where it has been obtained from the ore, and be allowed to flow into the improved furnace or furnaces hereinafter described, or it may be obtained from any convenient form of re-melting furnace, or the iron may undergo a previous partial refinement in the old or in any other convenient way.

"I desire it to be understood that I do not confine myself to the precise details herein specified, provided that the peculiar character of my invention be retained; but what I do claim, firstly, is the conversion of fluid crude iron into steel or into malleable iron, by exposing the metal to the decarbonizing action of currents of air in furnaces, through which the metal is allowed to fall for that purpose. And also, in the manufacture of iron and steel, the alternate rising and lowering of two furnaces, so as to allow the fluid metal to flow from one to the other in the manner, and for the purposes, before described.

"Secondly, I claim in manufacturing malleable iron and steel from crude iron while still in a fluid state, the use of revolving furnaces, having apparatus in the interior for the purpose of elevating portions of the metal, and allowing it again to fall in streams or showers when exposed to the action of currents of air passing through the furnace.

"Thirdly, I claim, in the manufacture of iron and steel, the suspension of the fluid metal in the furnace by means of centrifugal force generated by the rotation of such furnace, and the forcing into, through, or upon the fluid metal so suspended currents of air or steam.

"Lastly, I claim the manufacture of bars, rods, or plates of steel by the cementation of bars or rods of malleable iron that have been obtained by the direct conversion of crude iron into malleable iron, and while still in a fluid state cast in suitable moulds."

Patent dated February 12th, 1856, claims:—

"The conversion of molten crude iron or of re-melted pig or finery iron into steel or into malleable iron, without the use of fuel for reheating or continuing to heat the crude molten metal, such conversion being effected by forcing into and among the particles of a mass of molten iron a current of air or gaseous matter containing, or capable of evolving, sufficient oxygen to keep up the combustion of the carbon contained in the iron till the conversion is accomplished."

Since the above patents were granted the patentee has taken out several others relating to the same processes.

The apparatus employed consists of a vertical iron cylindrical vessel, the interior of which is lined with fire-brick. Near the base of the vessel is introduced a series of tuyeres, through which the air is forced. The blast-pipe communicates with an annular belt, in which the pipes carrying the tuyeres are inserted. Above the throat of the furnace an opening is made for the exit of flame and gaseous products, and from this opening the eruption of slag takes place during the boil. A tapping-hole, and a man-hole for facilitating the cleaning and repairing the interior of the vessel, are provided, and the metal from the blast furnace flows through an opening about midway between the base and throat of the vessel. The metal having been run in and the cold blast turned on, rapid ebullition ensues; an intense heat is generated, caused, according to the specification of the patentee, by the oxygen of the blast combining with the carbon contained in the iron; the impurities are thrown up in the form of slag, and in the course of about half-an-hour from the commencement of the process the refined metal is run off into ingots.

The blast employed is of the pressure of about 8 to 10 lbs. on the square inch, and from 6 to 12 tuyeres are used for the distribution of the air, their united area being equal to about two square inches. The blast being introduced below the molten metal, so that it may be thoroughly disseminated and forced through it in minute jets, it follows that the air must be compressed with a force greater than will balance the weight of a column of molten iron of a height equal to the depth of immersion of the tuyeres below the surface of the metal.

By the Bessemer process all the effects of puddling are proposed to be produced in 30 or 35 minutes, on large quantities of iron, by the use of air alone, and without fuel. A large quantity of air is forced into the fused cast-iron, and a high temperature induced, as stated by the inventor, by the combustion of the carbon contained in the iron, but really to a large extent by oxidation of the metal itself.*

The metal being merely decarbonized to a certain extent, without any mechanical manipulation, no fibre is produced; and it is also a point for particular inquiry as to how far cinder and other impurities may be removed from the metal by this process without its being subjected to the usual manipulation.

There is no probability that the Bessemer process will take the place of puddling in the production of malleable iron. This process produces a kind of refined and partially decarbonized metal; but nothing approaching fibrous malleable iron; it has a brilliant lustre, the metal being crystalline and porous. Now it is well known in practice, that to produce good fibrous wrought iron, the pig must be slowly boiled at a low heat, with a tough cinder, and be subjected to active manipulation—all which points are exactly reversed in the Bessemer process.

It has been stated that by this process wrought iron was to be produced at a price far below that at which it can be made by the methods at present in use, but even supposing that wrought iron could be manufactured by the Bessemer process, it is very questionable whether the method would

---

* "I shall give a short recital of an experiment, which I had the honour to exhibit some years since, before the late Martin Foulks, Esq.; the then worthy President, and several other respectable members of the Royal Society. I ordered a round ball of iron, weighing about four or five pounds, to be fixed for convenience at the end of a long bar of the same metal. The ball was put into a large fire at one forge, (for there is need of two to make the experiment;) it was there heated to so great a degree, that it was almost ready to melt, and indeed till the sulphur, (or cinder, as the workmen choose to call it,) was absolutely in a state of fusion. Then being removed to another forge, where there was no fire, and there being dexterously applied by one man to the nose of a large pair of bellows, and another man being placed to blow the bellows, and force the condensed air with all his might into the pores of the heated ball; in a very few seconds the heat of the ball was increased to such a degree of intenseness, as to make the iron drop like melted wax. . . . In this manner I have sometimes run off from the ball, four or five ounces of the metal thus reduced to a . . . . perfect calx or crocus of iron.—*H. Horne. Essays concerning Iron and Steel.* London, 1773.

not be found much more uncertain and expensive than puddling, when we take into consideration the cost of the coke for re-melting the pig-iron, engine-power for blast for re-melting furnace and finery furnace, waste of iron, wear and tear, and labour.

The process of making steel direct from cast-iron was known and practised 150 years ago, and perhaps even at an earlier period: the methods employed were, either to direct a cold blast upon the cast-iron brought down into the hearth of the smelting furnace, or to re-melt the pig-iron, and treat the fluid metal in the same way; but it was perfectly well known that the steel produced by either of these processes was of a greatly inferior quality to steel converted from good bar-iron.

An earlier patent for a very similar process to Bessemer's, and which will require no detailed notice, was obtained by J. G. Martien, of Newark, New Jersey, U. S., for improvements in the manufacture of iron and steel. Patent dated September 15th, 1855.

The specification states the object of the invention as being—"The purifying of iron when in the liquid state from a blast furnace, or from a refinery furnace, by means of atmospheric air, or of steam, or vapour of water applied below, and so that it may rise up amongst, and completely penetrate and search every part of, the metal prior to the congelation, or before such liquid metal is allowed to set, or prior to its being run into a reverberatory furnace, in order to its being subjected to puddling, by which means the manufacture of wrought iron by puddling such purified cast-iron, and also the manufacture of steel therefrom in the ordinary manner, are improved. In place of allowing the melted iron from a blast furnace simply to flow in the ordinary channel or gutter to the bed or moulds, or to refinery or puddling furnaces, in the ordinary manner, he employs channels or gutters, so arranged that numerous streams of air, or of steam, or vapour of water, may be passed through and amongst the melted metal as it flows from a blast furnace. He prefers, in carrying out his invention, that the ordinary process of refining iron by the use of a refinery furnace should be dispensed with, and that the purifying of the iron should be accomplished by subjecting the melted iron from a blast furnace before it is allowed to congeal to the action of streams of air or steam passed up through and amongst the melted metal; at the same time he would state, that where it is preferred by others still to resort to the ordinary refinery process by re-melting, then his invention is to be applied to the melted metal as it flows from such furnace to a bed or moulds, in like manner to what he will now describe as applicable to a blast furnace. The channel or gutter employed may be of any suitable material; but he prefers it to be of cast-iron, the bottom part being made hollow, to receive steam or air, or both. This gutter is perforated with numerous holes, which he prefers to be inclined, so that the streams of air or steam may be forced through the melted metal (as it flows along the gutter) in an oblique direction, but, by preference, in the direction in which the metal flows. This, however, is not essential, as the streams of air and steam may be passed directly up through the melted metal, or the holes may be inclined in the opposite direction, so as to oppose the flow of the melted metal. When hot blast or cold blast is used, he prefers to connect the hollow bottom of the gutter with the air pipes used to supply the blast, and when steam is employed he connects the hollow bottom of the gutter with the boiler used. By these means the air or steam introduced in the hollow bottom of the gutter below the metal will rise up and be forced through it in numerous streams; or, in place of the gutter being the means of applying streams of air below the fluid iron as it comes from a blast furnace, the moulds or beds into which the melted iron is received may be arranged with means for introducing air or steam below the melted iron, and to divide such air or steam into numerous streams, so that the iron may be purified thereby after it has come from the blast furnace and before the congelation of the liquid metal takes place. The gutter or channel may be covered over for any part of its length, and arranged in a suitable manner to admit of heat being applied to the metal therein; and such is also the case with respect to the moulds or bed, in order that heat may be continued to the fluid metal after it has left the blast furnace, and whilst the process above described of purifying the metal is going on. The iron thus purified may be allowed to cool in the moulds, or it may be run from the gutter, channel, or receiver, into a reverberatory or suitable furnace, to be highly heated therein, and may be puddled in the ordinary manner. He would remark that he is aware that it has before been proposed to use streams of steam in puddling and refinery furnaces in such manner as to come in contact with the surface of the melted metal therein, and it has also been proposed to introduce steam below melted iron when puddling the same. And he mentions these cases in order to state that he makes no claim thereto; but what he claims is, the purifying iron from a blast furnace or a refinery furnace whilst still in a melted state."

There is no danger, as is frequently suggested, that in consequence of the much greater attention paid to quantity than to quality of iron made by British manufacturers, that any appreciable portion of the iron trade will pass into the hands of continental manufacturers, for there is a large and increasing demand for rough common iron at as low a price as possible, and the lower the price, consistent with the production of a suitable article, the greater will be the consumption, and with our supplies of coal and iron ore, and average rate of wages, we cannot be injuriously affected by the competition of our neighbours: but it may be reasonably doubted whether the rage for extreme low prices does not act injuriously on the consumer as tending to the production and use of iron of so indifferent a quality as not to have fair average strength and durability, consequently requiring renewing sooner than should be the case, and thus causing eventually more outlay than would have been occasioned by the use of a better material in the first instance.

Iron of any quality may, by adopting proper measures, be made in Britain; but the greater demand being for fair ordinary descriptions, and charcoal being with us a very expensive fuel, it is probably, in a national and commercial point of view, more advantageous for us to import from countries having rich and pure ores and abundance of wood for fuel, the comparatively small proportion of high quality iron that is required for finer purposes, than to attempt to manufacture such qualities ourselves.

MISCELLANEOUS PROCESSES.

TIN PLATES.

The iron from which tin plates are made should be grey pig, of good quality, which is usually refined with coke in the ordinary way, and is then converted into malleable iron, not at the puddling furnace, but by the use of wood charcoal, in a charcoal fire or kind of refinery or bloomary. The charcoal fire is blown with blast, and the iron is heated in contact with the fuel. As soon as the iron has come to nature and been worked up into balls, it is taken to the hammer, and either drawn into slabs or blooms, or, after being shingled, is rolled into rough bars; or the balls are hammered into rough plates about ¾ inch thick, which plates are broken or cut into convenient sized pieces for being again re-heated and rolled into rough bars. These rough bars, which are about 5 inches wide and 1½ inch thick, are heated in a hollow fire, where coke is the fuel, which is blown with blast, but the iron does not come in contact with the coke; when sufficiently heated the bars are subjected to the action of the hammer, and are then rolled at the same heat into a bar 6 inches wide, and about ⅜ inch thick. This last bar is rolled into sheet-iron of such size and thickness as may be necessary for the description of tin plates to be manufactured.

The next part of the process is that of cleaning the sheets of iron preparatory to their being tinned: this is done in the following manner:—the sheets are folded or bent at an angle sufficiently for them to stand on their edges, thus ∧: they are then immersed for a few minutes in a pickle of diluted muriatic acid, and are afterwards stood on their edges on the hearth of a reverberatory furnace until heated to a dull redness. This process loosens the adherence of all particles or scales of oxide and other impurities, and is technically called "scaling." When cold, the plates are taken by their corners in a pair of tongs and beaten on a cast-iron slab, for the purpose of detaching the scales and flattening the plates, which, after the scaling process, have a peculiar mottled appearance. The plates are next subjected to the process of "cold rolling," that is, they are passed singly between a pair of very smooth chilled cast-iron rollers, called "planishing rolls," and which, when in good order, are so true that a single hair laid upon the plate as it is being passed through the rolls will leave a perceptible mark on the plate. The process of cold rolling not only leaves the plates perfectly smooth, but increases their density and hardness to such a degree as to render it necessary to subject them to a subsequent softening or "annealing."

Annealing, as usually performed, consists in gradually heating the articles to be softened to a red heat, and then allowing them to cool gradually: the mode of action of this process being that it allows of the particles of the material forming a stable arrangement, or of recovering their proper arrangement or condition after such arrangement or cohesion of the particles of the material has been altered or destroyed through severe hammering, rolling, or other mechanical disturbance. If articles of iron are heated in contact with the air, a scale of oxide forms on the surface of the metal, which in some common rough articles may be a matter of small importance, but which would be a most serious drawback in annealing plates already cleaned and scaled, and the plates intended for tinning are therefore annealed in close cast-iron boxes, so as to prevent the oxidating effect of the air. After being annealed the plates are immersed for a few hours in a weak acid lye produced by the fermentation of bran in water, and subsequently they are subjected for a short time to the action of a pickle of diluted sulphuric acid and water, and are then scoured and placed in clean water in readiness for the tinning.

The plates to be tinned, after being properly prepared and cleaned, as already described, are placed one by one into a pot of hot melted tallow, they are then dipped into a cast-iron pot containing melted tin, upon the surface of which is a layer of hot tallow about 4 inches in depth. When sufficiently coated with tin, the plates are taken out one by one and placed on an iron rack so that some portion of the superfluous metal may drain off. The plates are next immersed in another pot of melted tin, any superfluous metal that adheres being dexterously brushed off each side of the plate by the workman, and they are then immersed in another grease or tallow pot, from which they are removed and placed on another grating until cold enough to handle. As the plates have been placed in the rectangular cast-iron pots or baths in which the tin is melted, in a vertical position, it follows that the coating of tin is thickest at the bottom edge, where the tin collects in the form of a "list" or "bead;" this list is removed by dipping the tin plate into a bath or pot having about $\frac{1}{4}$ inch in depth of melted tin at the bottom; when the list is melted by contact with the hot tin in the pot, a smart stroke with a thin stick detaches the bead of superfluous metal, and the operation of tinning is completed.

The plates are then cleaned from the grease adhering to them, by being rubbed in dry bran, and are then sorted, inspected, and packed in boxes for sale.

The above is the process of manufacture of the best description of tin plates, which are known by the name of "charcoal plates." An inferior quality is made without the use of charcoal for fuel in any part of the process, and these are designated "coke plates."

Thin sheet-iron is also occasionally coated with lead, and, to a large extent with an alloy of tin mixed with a greater or less proportion of lead.

GALVANIZED IRON.

THE name "galvanized iron" is that which has for many years been given to articles of iron when coated with zinc; the object of such coating being to preserve the iron from oxidation by the atmosphere. This oxidation, under ordinary circumstances, proceeds so rapidly as to prevent sheet-iron from being used for the covering of buildings and many other purposes for which it would otherwise be very suitable.

When iron is thoroughly coated with zinc the atmosphere of course has no direct action on the iron, but a thin film of sub-oxide is formed on the zinc coating, which sub-oxide of zinc is sufficiently hard to resist further oxidation, and to remain sound when subjected to considerable mechanical friction.

Galvanized iron, which is now very extensively used for roofing buildings, for rain-water gutters and pipe, and for the manufacture of a vast variety of articles for domestic use, besides the process being largely applied to the protection of all descriptions of iron-work, was first prepared to a small extent by a Frenchman named Malouin, in 1742, but the process of the application of zinc to coating iron appears to have been forgotten for a long period of time until resuscitated of late years.

Numerous processes have been invented and patented having for their objects the preservation of iron from oxidation, but of the whole number only two of them may be considered as possessing really useful and practical advantages. Iron may be coated in the humid way by voltaic deposit, by a solution of sulphate of zinc, or by a solution of the double salt of chloride of zinc and sal ammoniac and a weak galvanic current.

The following summary of the properties of the most important material in the galvanizing process may probably be well introduced in this place:—Zinc is a bluish-white metal, brittle, and has a lamellar crystalline structure. It melts at 773° Fah., and when this heat is exceeded the metal burns with a greenish-white flame, and white flocculent particles of oxide or flowers of zinc rise and float in the air. At 400° zinc is quite brittle; between 250° and 300° it is quite malleable, and can be rolled into sheets which retain their malleability when cold. Fused zinc rapidly forms an alloy with iron immersed in it.

The two methods of galvanizing or coating iron with spelter that are most largely pursued in this country, consist of applying the zinc by heat in a state of fusion, but they differ in the detail of the operation. In coating iron by the first of these two methods, the sheets or other iron intended to be galvanized must be first cleaned in brown vitriol and water. Sheet-iron is usually "scaled," that is, it is dipped into a weak solution of muriatic acid, and then heated to a dull red heat in a reverberatory furnace; the object of this operation being to remove the scale or oxide of iron which forms on the surface of the sheet. When the sheets thus scaled have become cold, they are dipped into a mixture of sulphuric acid and water, and moved about in it until the surface of the iron becomes bright: this process of "scaling" or cleaning being similar to that pursued in the preparation of iron for making tin plates; and the sheet-iron when cleaned may be kept for days or weeks bright and perfectly free from rust by being immersed in pure water.

The sheets or other ironwork, after being properly cleaned, are dipped into, or washed over with, a solution of the double salt of chloride of zinc and sal ammoniac, prepared as follows: twenty-eight pounds of sal ammoniac are put into a leaden cistern, with 12 gallons of muriatic acid, 24 gallons of water are then added, and subsequently also about 10 lbs. weight of melted spelter, hot, so as to granulate it, the whole being then covered up close. The articles to be galvanized only require to be immersed in this last mixture for two or three minutes, (if too large to be immersed they may be washed over with it,) and they may then be subjected to the final or zincing process by being dipped into the melted spelter.

The spelter is fused in a wrought iron vessel or bath, the joints of which must be welded instead of riveted. To prevent the oxidation of the spelter it is kept covered with some flux, sand or sal ammoniac being most commonly employed, or with a flux formed of resin and carbonate of soda, or different portions of the surface of the spelter are covered with different fluxes, kept separate by a piece of bar-iron across the bath: thus, sal ammoniac may be employed to cover that portion of the surface at which the articles to be coated are put into the metal, and damp sand used as a covering over that part of the surface when they are withdrawn: fatty substances may also be used as a flux.

Large pieces of iron-work must be warmed before being immersed in the melted spelter to prevent the temperature being too much lowered. Some articles may be put into the hot zinc wet, but great care is necessary in putting any wet iron-work into the melted zinc, or the fused metal may be thrown about in all directions, especially if the articles immersed have any irregularities on their surfaces; if there are holes, recesses, or flanges, the iron must be dried. The effect of using the mixture of chloride of zinc and sal ammoniac just described, is that it assists to prevent the hot metal being thrown about when wet iron-work is immersed in the bath, and the work takes a better coating, and is finished more quickly than if it were not used. As soon as the iron has obtained a coating of zinc it should be withdrawn: iron-work should never be allowed to remain a moment longer in the zinc than imperatively necessary, because the iron rapidly deteriorates the spelter. As little as possible of sal ammoniac should be used on the surface of the zinc, both for the sake of economy and for quality of work. If much sal ammoniac is used, the iron-work will require to be immersed and washed in cold water after it comes from the bath, or it will be liable to turn black and otherwise discolour; and if it is washed in cold water, the finished work will not have so bright and clear an appearance as would have been the case if allowed to cool gradually, without being wetted when taken out of the zinc.

It is advantageous to have all the cleaning pickles heated, as their operation is thereby increased. The mixture into which the iron is immersed immediately previous to the zincing process should be heated.

The spelter employed should be perfectly pure; but however pure the zinc may be, it soon begins to be affected by the alloy that forms between the hot zinc and the iron dipped into it, and still more so by the alloy formed with the zinc and the iron pan or bath itself. This deterioration of the spelter is a serious item in the cost of galvanizing, and the spelter, with even a very small per centage of iron in it, is not suitable for making yellow brass of a colour and quality suitable for general brass-foundry work.

Cast-iron has been used for vessels in which to fuse zinc, but the rapid formation of an alloy of spelter and cast-iron is such as completely to spoil the spelter, and render it useless for galvanizing with: this objection was endeavoured to be overcome by lining the cast-iron bath with clay, but the effect was unsatisfactory, and now wrought-iron baths are employed; and even with wrought iron the zinc rapidly forms a peculiar alloy, though not nearly to so great an extent as with cast-iron. Earthen crucibles or baths have sometimes been employed, as also placing fused lead at the bottom of the iron bath to prevent the contact of the spelter with the bottom. The zinc does not combine with the lead, but floats upon it.

Coke or charcoal is the most convenient fuel for heating the baths or pots.

When large objects are to be zinced they should be first heated in a reverberatory furnace, after having cleaned them with the acid and scoured them. The screws or other objects to which the zinc is not required to adhere are covered with a thin layer of clay, and when there are holes they are closed with plugs or pieces of wood.

In coating nails and similar articles they are first placed in a basket of iron wire, or a vessel pierced with holes. The basket or vessel is then placed in the molten zinc, and the bath of metal covered with a coating of sal ammoniac. The basket being taken out of the bath is shaken with care in order to get rid of the excess of zinc. For the same purpose, the articles to be galvanized may be placed in a cylinder pierced with holes, turning on its axis, which has been heated to a degree sufficient to prevent any superfluous zinc from adhering in the holes or cavities. The articles are sometimes thrown into water at a moment learned by practice, for the purpose of detaching the superfluous zinc by the sudden cooling.

To finish large articles the file or scraper is employed to remove inequalities, afterwards polishing with pumice-stone or sandstone.

Cast-iron articles deteriorate the melted spelter much more rapidly than wrought iron articles, and the consequent expense of zincing cast-iron may be considered as about double that of zincing wrought iron. Cast-iron articles that are required to be galvanized, and to have also a good face, should be cast of good metal and in iron moulds.

The double salt of sal ammoniac and chloride of zinc has the remarkable property of very greatly facilitating the operation of covering iron or copper with tin, zinc, or lead. The effect of this double salt in soldering or tinning is probably due to the greater affinity that zinc has for oxygen than for chlorine, whilst on the contrary the other metals (iron, &c.,) have a greater affinity for chlorine than for oxygen.

The other process of galvanizing, before referred to, consists in giving to the sheet-iron to be galvanized a slight coating of tin previously to subjecting it to the action of the zinc, and which is done in the following manner:—A quantity of chloride of tin is prepared by dissolving granulated tin in muriatic acid, and about fifty times its bulk of water is added to the chloride, in a wooden vessel: on the bottom of the vessel small pieces of zinc are strewed, and upon these is placed a layer of sheets of iron previously scaled and pickled, then again a sprinkling of zinc, followed by another layer of iron, and thus alternately until the cistern or trough be filled. The cistern being thus charged contains all the requisites for forming a sufficiently active self-acting voltaic battery; the zinc and the iron to be coated forming the pairs of dissimilar metals, while the salt of tin, the substance from which the iron is to receive the coating, acts as the exciting matter: and in about two hours the sheets of iron will have received a sufficient coating of tin by galvanic deposition.

It should be borne in mind in coating metals by voltaic deposit from aqueous solutions of other metals, that if the battery is very active, and the deposition consequently rapidly made, the coating of metal obtained will have little or no attachment to the metal on which it is deposited: this result has no doubt been frequently observed by most persons in their first attempts at electrotype and similar processes.

After the sheets of iron have received a sufficient coating of tin, they are subjected to the zincing process by being passed through wrought-iron rollers, rotating by means of steam or other power in a shallow bath of melted spelter. The use of these rollers is to draw the sheets of iron evenly and quickly through the hot zinc: as soon as the sheet of iron has passed through the rollers, which operation requires only a few seconds of time for its completion, the galvanizing is completed, and the sheet is placed on end to cool.

By the first of these two processes the zinc forms to some extent a kind of alloy with the sheet-iron it is employed to coat, and the iron is rendered somewhat rough, harsh and brittle; by the second process, or that of giving a very slight intermediate coating of tin, the zinc does not come so immediately in contact with the iron, and when good well-annealed sheet-iron is subjected to this tinning and zincing process, its malleability is not interfered with, and it may be readily wrought into utensils without cracking, and it also has a perfectly smooth face.

The method of coating iron wire with zinc, as done for the electric telegraph and other purposes, is to place the coil or hank of wire upon a drum or cylinder capable of revolving upon its axis, and after leading the wire under a fork or bar placed in the bath so as to immerse the wire in the melted zinc, the end of the wire to be coated is fastened to another reel or drum, to which a rotatory motion, at any required speed, is imparted by a steam-engine or other power. When this latter reel or drum is set in motion, it winds off the wire placed on the first-mentioned drum, drawing the wire evenly and regularly through the melted spelter and flux, and coiling up the coated wire in hanks of any desired size, according to the diameter of the reel employed. By this means several distinct coils of wire may be coated at the same time, attention being given to see that they are all immersed in the zinc, and that in other respects the operation is proceeding properly.

The shape and size of the iron baths or vessels in which the spelter for coating various sizes and descriptions of ironwork is melted, is a matter requiring considerable attention, as it is exceedingly desirable to have no more zinc in a molten state than necessary, and to have as small a proportion of it as possible in contact with the iron bath.

Great diversity of opinion exists among engineers as to the propriety of using galvanized iron for roofs, railway and other sheds, &c., and many instances have been cited where the process of galvanizing seemed to have little or no effect in preserving the iron from oxidation. On the other hand, the durability of the wires of the electric telegraph, of roofs exposed to the action of sea air, of galvanized welded tube for the conveyance of water and gas, and the successful application of the process for many other purposes, is proof that it does, under other circumstances, answer the desired end. There can be no doubt but that the circumstances under which it may be employed will, as with everything else, have considerable effect on the result, and that, in common with other metals, it should not be used, without being either tarred or painted, in localities where the air is impregnated with sulphurous acid or other acid fumes.

STEEL.—HARDENING AND TEMPERING STEEL.—MALLEABLE CAST-IRON.—CHILLED CAST-IRON, &C.

Steel is a carburet of iron, being iron containing 1 to 1½ per cent. of carbon; whereas soft foundry iron, also a carburet, contains as much as from 3 to 5 per cent.* Steel differs from malleable iron in the very remarkable property that the former possesses of becoming hardened upon being suddenly cooled; whereas, good bar-iron, if heated and suddenly cooled by immersion in water, should not be increased in hardness and brittleness by that operation. Cast-iron and steel, to a certain extent, correspond in their qualities, and cast-iron possesses the property of being superficially hardened by sudden cooling. This property of cast-iron is taken advantage of for making "chilled castings," or hardening the whole, or only certain portions, of the surface of castings for various purposes, as bushes of naves of wheels, rolls for rolling sheet metals, and numerous other purposes where great hardness is desirable. These "chilled cast-

---

* Cast irons contain from about 2·25 per cent. to 4 per cent. of carbon, and in some instances as much as 5 per cent.

Carbon may be present in cast-iron in two distinct states or conditions, i. e., it may be chemically combined with the iron, or may be present as a mechanical admixture only, in the form of plumbago or "kish;" and carbon may be, and frequently is, present in both these states in the same sample of cast-iron.

Gray pig-irons contain more uncombined than chemically combined carbon, and white pig irons contain only chemically combined carbon.

The per centage of carbon in steel varies from 0·50 to about 2 per cent., cast steel usually containing from 1 to 1·50 per cent. Blistered steel sometimes contains as much as 1·75 per cent. of carbon.

Good malleable iron frequently contains a proportion of carbon, up to 0·20 per cent. If the quantity of carbon in malleable iron amounts to 0·50 per cent. it then becomes a very soft steel.

The principles upon which depend the peculiar and valuable property possessed by steel and cast-iron, of becoming hardened when suddenly cooled, are not known.

The ascertaining the quantity of carbon present in the carburets of iron, is a difficult and tedious operation of chemical analysis. Professor Brande considers it doubtful whether any true atomic compound of iron and carbon can be obtained.

ings" are made by pouring the fused cast-iron into iron moulds, instead of moulds formed in sand or loam, as for ordinary castings, or where a portion of a casting only is required to be chilled, the mould of that portion is formed in iron and inserted into the sand or loam mould. Chilled cast-iron resists the action of a file almost like hardened steel, and cast-iron left to cool slowly in the sand or loam mould is softer than if the mould were opened and the casting thereby suddenly cooled, and castings in which strength and toughness are desirable should always be allowed to cool in the mould. There is a peculiarity in the process of manufacture of chilled castings that deserves notice, and that is, it is found in practice that chill moulds should be heated "black hot," and not used cold, for that, when the iron chill is heated, the process of chilling is more complete than with a cold mould. Under all circumstances the exterior coat of iron castings is harder than the interior.

Hardened steel may be again softened by being heated and allowed to cool gradually, and cast-iron may be made to become tough, soft, and malleable, by a kind of annealing also accompanied with some extent of decarbonization.

Articles of cast-iron intended to be converted into malleable annealed cast-iron, should be cast from good iron, but containing no more carbon than sufficient to give the necessary degree of fluidity when melted. The castings when cold are hard, brittle, and have a white crystalline fracture. They are enclosed in iron boxes, and surrounded with pounded ironstone, some metallic oxides, scales from the forge, lime, or other absorbents of carbon; when filled, the boxes or cases are luted and exposed to the heat of a furnace for a certain time, perhaps as much as for 3 or 4 days, and then allowed to cool gradually.

The quality of the iron employed, the size of the articles, the nature of the composition they are heated in contact with, and the length of time the operation may be continued, will more or less affect the result. By the process of annealing, and also withdrawing the carbon from the cast-iron articles, they are, to a greater or lesser depth, converted into wrought or malleable iron, but they are destitute of the fibre that rolled or hammered iron possesses. Thin castings and nails, &c., may be converted into malleable iron all through their substance, but larger pieces will be found to have a centre or core of cast iron.

Reaumur, in his account of experiments for producing malleable castings, published in 1722, has the following:—"On the occasion of my commencing the annealing of cast-iron on a large scale, a circumstance occurred which appears to me worthy of notice, and which would have been difficult of explanation but for the observations previously mentioned. Amongst the objects I placed in the furnace were several large cast-iron door-knockers, very heavy in consequence of their size and thickness. On withdrawing them from the furnace I was not a little surprised to find them light: solid and heavy as they were when put in, they had now become hollow, being now nothing more than twisted pipes: all their interior was empty: they had, however, undergone no change on the exterior, with the exception of losing some of the ornamental parts, which had possibly scaled off. When looked at attentively, several little holes were visible, through which the metal in the interior, having become fluid, had escaped. It was not surprising that the knockers had become lighter, a portion of the material of which they were composed having run out, but it appeared to be the interior portion, and even the centre, which had been rendered fluid, whilst the exterior portions had preserved their solidity. It is contrary to natural order that fusion should commence at the interior: the interior can only receive heat from the exterior, and at the most can only become as hot, certainly not hotter. For the explanation of this fact it is sufficient nevertheless to remember that malleable iron is infusible in an ordinary fire, and to suppose that the heat in my furnace was not sufficient to render the iron fluid until a certain thickness of the knocker had been softened [decarbonized] and had become converted into malleable iron. The heat having been then increased, the knockers preserved their external form, whilst their interior, consisting of cast-iron, completely enclosed in a species of infusible iron crucible, had become fluid, and finding an outlet at those places where the external covering was least capable of offering resistance owing to its thinness, ran into the furnace, where the metal was found in a shapeless mass."

When malleable castings are subjected to the process of "case-hardening," or converting their exterior portion to a slight depth into steel, they will bear polishing, and a great variety of cutlery and hardware articles are made in this way, which are known by the name of "run-steel."

Steel is usually made by heating bars of malleable iron in contact with powdered charcoal, for some hours, at a red heat. The iron takes up 1 to 1½ per cent. of carbon, and becomes harder and also fusible; this is called "blistered steel."

"Shear steel" is blistered steel piled or fagotted, then heated and subjected to the action of the tilt-hammer. Cast steel is blistered steel fused in a crucible and cast into moulds. Steel that contains too much carbon may be deprived of any proportion of it by heating the steel in contact with oxide of iron or manganese. Steel having the peculiar and valuable property of becoming very hard and brittle when heated and suddenly cooled, and of being softened by being heated and slowly cooled, any desired degree of hardness may be obtained.

The usual practice of hardening and tempering steel is to suddenly cool the steel in water or other liquids, and then to subject the hardened steel to a greater or less annealing heat, and when judged to be of the required temper or softness, by immersing the steel in water or oil, or other fluid, the steel is cooled, and is thus prevented from becoming any further softened.

The colours formed upon steel in the processes of hardening and tempering arise from oxidation. A pale straw colour denotes great hardness, which passes to brown and purplish-brown as a somewhat softer state is attained. The next colour in order of softness is violet, which is followed by a deep blue colour if the annealing heat is continued. A heat of about 430° Fah. produces a pale straw colour; a deep blue is produced by increasing the heat to about 550° or 560°.

Steel may also be made directly from cast-iron by exposing it to an oxidizing process. The process of melting "blistered" steel in a crucible, and running it into ingots, or forming "cast" steel, was discovered in England about a century ago.

The most perfect and homogeneous steel is that which has undergone fusion, or "cast steel." Cast steel having the property of setting very rapidly when in a melted state, and with very little abstraction of heat losing its fluidity and become pasty and solid, and also requiring a very high temperature for its fusion, has, until recently, been but seldom cast into any but the plainest forms, such as round and square ingots, from which the desired form had to be forged; such ingots being cast in metal chills, (owing to the difficulty of preparing any other description of moulds capable of resisting the action of the hot steel,) which of course rapidly abstract the heat from the fluid steel.

By the patent process of E. Riepe, which is in use at the works of Naylor, Vickers, & Co., of Sheffield, steel is cast into any required complicated forms by running the fluid metal into moulds composed of a somewhat fire-proof earth, (and consequently a bad conductor of heat,) in which moulds the steel has ample time to cool slowly, and to fill even the finest and most ornamental parts. The material of the mould becoming stronger when exposed to heat, effectually resists the destructive action of the fused steel.

Heavy cast-steel forgings, such as shafts, cranks, axles, tyre-bars, locomotive double-crank axles, &c., of any form and size, are manufactured by this process; the article required being cast nearly to shape, and only receives sufficient forging to take off the chill and develop or close the grain of the steel, so as to produce perfect condensation and malleability of the metal. By this method complicated forgings in steel may be produced at very nearly the same price as similar forgings in wrought iron.

In the application of steel in place of wrought iron the sectional area of the articles may be reduced, and consequently they can be made lighter. Professor Redtenbacher, as the result of his experiments, gives the strength of forged cast steel as compared with wrought iron, as under:

Capability to resist tension as 7 to 3.
,, torsion 5 to 3.
,, flexure 5 to 4.

And as regards power of resisting compression the steel has still greater advantage.

Steel bells, cog-wheels, and a variety of articles, are also manufactured by the above process.

"Case-hardening" is in fact converting the exterior of iron into steel; this is effected by placing the work in a box or sheet-iron case, with animal matter, as hoofs, horns, bones, or skins, which are mostly charred, and with which materials the work should be covered everywhere half-an-inch thick: the lid is tied on with iron-wire and luted, heated quickly to a red heat for from half-an-hour to an hour, and then either cooled suddenly, or the work is hardened in a subsequent operation of being heated and suddenly cooled. Malleable cast-iron goods should be cooled in oil. Prussiate of potash, a salt (composed of two equivalents of carbon and one of nitrogen) made from animal matters, is used for case-hardening, the article to be hardened being heated and sprinkled with the salt and afterwards suddenly cooled.

Iron exposed to long-continued hammering, rolling under great pressure, or other severe mechanical operations, becomes hard, highly elastic, and brittle, when it is necessary either to discontinue the hammering or compression, or the metal must be softened by annealing—which process has already been adverted to in the section on the manufacture of tin plate. Bar-iron also is toughened by annealing.

A mixture, consisting of one part of powdered calcined iron ore, and eight parts of coke or lime, has been recommended to be used in annealing malleable iron, where superior results are desired. The articles to be annealed being enclosed in the above mixture, in cast-iron boxes, and luted, and then subjected to the heat of a furnace, and allowed to cool slowly.

ON THE EMPLOYMENT OF CAPITAL IN IRON-WORKS AND COLLIERIES.

THE importance of the British iron manufacture and the opportunities it affords for the employment of capital, are so great, and money is so frequently embarked in it by parties who are personally wholly unacquainted with this branch of our national industry, and in the vast majority of such instances with disastrous results, not only to themselves, but, in various ways, probably to all who may have the unhappiness to be connected with them, and as the careless, ignorant, reckless, or unprincipled proceedings of a few, or even of a single individual, may be, and often is, productive of a large amount of disappointment, loss, and misery, the writer proposes to append a few remarks on this branch of the subject, and endeavour to point out some of the principal causes that lead to such frequent failure, so that capitalists contemplating such investments may be enabled to avoid them, or by having their attention called to the subject may not pass them over without due inquiry.

The principal branches, commercially speaking, into which the iron manufacture is divided, may be enumerated as follows:—1st. The smelting pig-iron from the ore. 2d. Manufacturing the pig or cast iron into wrought iron, as bars, rods, sheets, &c., which is done at the forge and mill; and 3d. Casting the pig-iron into articles of general use, either for domestic purposes, as grates, ranges, balconies, &c.; or for building and other purposes, as girders, beams, pipes, bridges, tanks, &c., which is carried on at the foundry. These branches of business are sometimes carried on independently of each other, sometimes the whole are carried on together at the same works, or any of the two are occasionally combined. There are many minor subdivisions of the manufacture, but the above principal distinctions will be sufficient for the present purpose.

It is generally the case where smelting of iron is carried on, that the manufacturer raises his own coal and ironstone, and sometimes limestone, and makes his own coke, fire-brick, &c., and then either sells his pig-iron to the forge and mill or foundry proprietor, or converts it himself into wrought iron or foundry goods.

In the generality of cases forge and mill proprietors purchase the pig-iron and the coal they require, from other parties, and make a profit by converting the pig-iron into bars, rods, sheets, &c., and the iron-founder also usually purchases the iron and coke he requires, making his profit by converting the pig-iron into gas and water pipes, bridges, beams, &c.; but there are variations in the method of proceeding, and even in some few instances parties engaged in iron-smelting purchase the whole of the ironstone, coal, limestone, fire-brick, &c., they require. Of course by this latter method of procedure works may be undertaken with a smaller amount of capital than would be needful in the case of opening up minerals; but there is also less opportunity of making large profits, as when iron rises in price, the price of all the necessary materials rises also, and when iron happens to be low, although the price of the materials would fall also, still a profit would be made upon them by the seller. In the case of works raising the minerals for themselves—supposing of course they are of suitable quality, and worked at a moderate cost—there is no intervening profit, and when iron is high in price the profits made are very great, and even when iron is low it is still made at the minimum of expense, all the materials being procured at cost-price.

There are two main causes of want of success in establishing profitable ironworks: the one, injudicious selection of sites, as affecting carriage, and quality of minerals, royalty,

&c.; the other, want of judgment in carrying out works even when the situation, quality of coal and other minerals, facilities of carriage, and arrangements as to royalties, &c., are of a favourable character.

The conditions necessary to be borne in mind in making selection of a spot for establishing smelting works, and, indeed, in some degree, any other branch of iron manufacture, are, the possession of suitable coal, and which can be worked at a moderate cost, ironstone of average quality, facilities for carriage, both for sending the manufactured iron to market and for importing ironstone, limestone, fire-brick, timber, and general stores, when required. The minerals must not only be of suitable quality, but their extent must be ascertained, as also their depth below the surface, their dip or angle of inclination, and freedom from faults, dislocations, and disturbances, as a great dip or angle of inclination causes incalculably more trouble and expense in working than when the strata are nearer the horizontal, and a fault is often the cause of a complete change in the position and consequent value of the minerals. The royalty, galeage, or rate to be paid to the lessor for permission to work the same, must be fair and moderate, and the terms of the lease, as relates to dead rent, (or payment in case the royalty does not amount to a certain sum per annum,) reasonable. Proper provision should also be made for the lessee to surrender his lease if he should find it necessary to do so. There must also be a good supply of water available; the lease should include permission to use, on easy terms, any stone, clay, sand, or other materials that may be useful in carrying out the works, and the terms for damage done to the surface in erecting works, making roads, tramways, water-courses, reservoirs, &c., and depositing cinder and other refuse should be clearly defined. The subject of way-leave, or right of ingress and egress, especially if it should be necessary to bring any material from adjoining or neighbouring properties, should have full consideration, so as to prevent any cause of difference or undue expense on this point.

The depth of the minerals below the surface is of less importance than their being horizontal, regular, and of a thickness for working profitably. Coal beds, or seams, from 3 feet 6 inches to 6 feet in thickness, are on the whole most advantageous; each foot in thickness will produce about 1,000 tons per acre, and a very usual royalty is 6d. per ton; 2 feet 6 inches, and 2 feet, and less, are thin seams for coal, but it is occasionally worked when only 12 to 16 inches in thickness. The nature of the strata forming the roof or covering of the coal, and the floor, or strata under the coal, is of great importance, as when they are firm the coal can be extracted with much less expense for timber and labour than when they are soft and yielding: freedom from fire-damp is also an advantage; and an important point is the quantity of water that may be met with, and which may possibly have to be pumped out of the mine; as the erection and maintenance of a pumping engine is a heavy undertaking, unless a considerable area of profitable minerals is unwatered by it.

The ton upon which royalty and way-leave are usually computed is the miner's ton of from 21 to 23 cwts., as may be arranged, but whether this is strictly legal may admit of a doubt.

Ironstone is worked sometimes when only 8 to 10 inches in thickness, and each inch in thickness, of good ironstone, may be considered to yield about 200 tons per acre; when several courses occur close together, the cost of labour for raising is proportionably small, and such ironstone is consequently very valuable.

We will suppose that the selection of a locality for establishing works has been made, that the site has either been leased or purchased by the adventurers, and operations commenced; and we will now turn to the consideration of the main cause of the failure of such undertakings, viz., want of proper caution and judgment in prosecuting the adventure. The axiom usually laid down, and acted upon, by parties entering into such undertakings is, that the more iron made the larger the profit. It is clearly demonstrated, on paper, that the profit, per ton, on a make of one hundred tons, is so much, and that consequently, if the make is five hundred tons there will be five times the profit, and if the make is one thousand tons, there will necessarily be ten times the profit, not much more labour and trouble in conducting the larger than the smaller concern, and the per centage of cost of superintendence, rent, and other current expenses, will bear in a much smaller ratio upon the larger make. Now there is some appearance of reasonableness in all this, and the view taken would be correct, if there were the capital, the ability, and the opportunity for carrying out the intention, but any one of these being wanting, or not able to fulfil its own share in the undertaking, disappointment and loss will inevitably be the result.

It not unfrequently happens that, with respect to the terms of the lease or purchase, important points are neglected, or arranged in a manner unfavourable to the future prosperity of the concern: but if this is not the case, a very fruitful source of loss are bad arrangements for opening up the mineral resources of the property, especially when, as is usually the case, considerable haste is made in commencing operations.

Bad arrangements in planning the furnaces and other appliances are another great source of loss; and want of care in proportioning the various mineral workings, so as not to have always a regular and sufficient supply of all materials for the furnaces, frequently causes much annoyance, interruption to the works, and consequent loss.

Other errors sometimes made in starting works are, to have furnaces too large for the engine or other power, and which are consequently never efficiently worked; insufficient number of coke ovens to furnish a regular supply of coke of proper quality for the furnaces; deficiency of steam, owing to having too small boiler surface; deficient arrangement of tramways, inclines, &c., causing unnecessary haulage, this latter being a most serious drawback, as for every ton of pig-iron made, there are at least six tons of material to be moved; depositing spoil, cinder, and other refuse in such spots as to render it needful to incur the expense of their removal at some future time. But perhaps the main difficulties and losses in such undertakings, may be considered as mostly arising from erecting works of such magnitude, as to swallow up at once so large a proportion of the whole capital of the undertaking as to leave little or nothing for conducting the commercial business of the enterprise; the consequence being that sales of iron have to be made as fast as it is produced, to meet current expenses, at whatever may be the market price. No concern in such a position can prosper; it is at once placed in a state of complete embarrassment; in a time of highly remunerative prices it may be able to pay its way, but works that cannot do a great deal more than this in good times will be wholly unable to meet the pressure of bad times and a fall in prices; when such occur it will at once be brought up, and although temporary assistance may be procurable on security of the works, lease, &c., experience has shown that it is not likely, nor hardly possible, that such loans can ever be repaid from the profits of the works; and should the mortgagees enter on possession, they will most probably find that they have a very unavailable security, and that their first loss is the least and best.* The next step in such concerns is either that they are shut up and abandoned, the whole of the capital having been lost, or some other parties purchase the plant for a comparatively small sum, and prosecute the works, in some instances, with profit, but in other instances with a further loss of capital, and possibly a new firm or company again purchase the plant and commence anew on the ruins of their predecessors.

---

* The following valuable remarks are from the leading article of the Times of November 15th, 1856, upon the occasion of the Bank of England raising their rate of discount to seven per cent.:—“ The value of money is still liable to great fluctuations, which must tell on those who assume a low and uniform value. Every man in trade ought to have a sufficient reserve, perfectly accessible. That was the old maxim. It is still the maxim of our best tradesmen. We may have particular reasons to lament the nonobservance of the rule in some firms that have a strong claim on the interest of society, but our regrets cannot alter the case, and arrest the sure operation of the laws of trade.”

"Then they began to build, and build,
And would not to my counsel yield,
To make a small beginning;
But built a large expensive place,
Wherein to run a random race,
Which hinders men from winning."
Short Story of a Long Life.

The above quaint lines, by one eminently successful through a long life, and who raised himself by his industry, perseverance, and prudence, from the station of a labourer to a high position and great wealth, are well worth the serious attention of the capitalist embarking in the iron manufacture. A late eminent South Staffordshire ironmaster commenced manufacturing, on his own account, at a work capable of turning out but ten tons of bar-iron weekly; but by judiciously extending his operations as his capital increased, he subsequently attained wealth and a wide reputation.

In calculating the *cost* of the various materials, it often happens that erroneous views are taken, and incorrect data employed, through want of knowledge or judgment; thus, for instance, in the cost of fuel, we frequently meet with the statement that the coke costs so much per ton, i. e., so many cwts. of coal at a certain price, wages for burning, and delivery at the furnace; the price of the coal being based on the amount paid per ton for cutting and raising, for delivery at the coke ovens, and for royalty: now the cost of the coal arrived at from such data is altogether erroneous. Not only should the cost of cutting and raising, royalty, and delivery at the ovens be included, but also a proportion of the outlay for sinking pits, driving levels, headings, airways, &c., erecting pumping and winding engines, engine-houses, making tramways, inclines, &c., as capital has been expended, and altogether sunk, in winning and opening up the minerals, in addition to the cost of cutting, raising, &c., so that instead of the two or three items we so often see giving a temptingly low price as the cost of the coal, upon consideration we shall find the items of cost expand into something like the following:—

Royalty.
Re-payment for outlay of capital sunk in winning and opening up the coal.
Interest on capital sunk in winning, &c.
Interest on capital employed in working the business, meeting current expenses, &c.
Cutting coal, and delivery at pit bottom.
Dead-work, as driving headings and air-ways, laying rails, maintaining roads, air-ways, ventilating furnaces, &c.
Pit timber, iron, brick, lime, and general stores.
Pumping and winding engine-drivers' wages, oil, tallow, &c.
Banking, i. e., landing, sorting or screening, and loading, at pit top.
General repairs to engines, boilers, pumps, and other machinery; renewal of ropes, corves, wagons, rails, &c.
Delivery at coke ovens.
Superintendence.
Contingencies, accidents, &c.
Profit.

In some cases, to the above items, surface damages, and way-leave, have also to be added.

It should therefore be borne in mind, that when it is proposed to make an outlay for the purpose of winning minerals, and the cost per ton of the material, when raised to the surface, is estimated to come to a certain sum, i. e., for labour, royalty, &c., that the estimate includes re-payment and the other items just referred to; for thousands of pounds may be expended in winning minerals, the greater part of such expenditure being, when the coal is worked out, inconvertible, or, in other words, sunk; therefore, the amount of capital thus laid out, must be added to the cost of the mineral.

The same remarks of course apply equally to the cost of ironstone, limestone, fire-clay, &c., and want of attention to these points causes most fallacious views to be entertained as to the cost of production of pig-iron, &c.

The purchase of established iron-works and collieries also requires great care and judgment, as although they may have the *prestige* of a good name for success, and although furnaces, engines, buildings and machinery, tramways, &c., may be in fair condition, and the terms of the lease favourable, large outlay may be needful in opening up a further supply of minerals, or the minerals may be so nearly exhausted as not to warrant a further employment of capital in winning them: or even if the quantity of mineral is considerable, great cost may have to be incurred in consequence of their not having been fairly and judiciously worked.

A statement that is often put forth as an inducement to capitalists to enter upon working minerals is, that they "crop out" on the side of a hill, and can consequently be obtained without the expense of sinking a pit, and that in many cases the water will run out from the level, and thus save the expense of pumping it. Now such statements must be received with great caution, for several reasons; for although it is true that the position and inclination of the minerals may, in some instances, be such as to present great advantages for working, in the generality of cases the advantages are not so real as first appearances may indicate, and serious drawbacks may also have to be encountered.

One of the chief disadvantages to be encountered in working minerals by "level," as it is called, i. e., driving a drift or gallery into a hill-side to intercept the mineral, is deficient ventilation, and where underground workings are badly ventilated nothing goes on right. The usual reason of this deficient ventilation is, that there is no opportunity of obtaining a vertical shaft to act as a chimney: the expense of making an air-shaft from the summit of the hill, where the elevation is considerable, frequently being the obstacle, and, if made, it at once brings us to much the same position as a colliery won by pits.

Another great disadvantage is, that when a drift has been extended to a considerable distance into the side of a mountain, and the mineral accessible by it is worked out, whenever a further extension of the drift is made, and fresh mineral obtained, it frequently has to be brought out through the first level, heavy expense being incurred in maintaining the drift; the cost of haulage, especially when the distance amounts to such lengths as a mile and upwards, is a serious matter, and the ventilation, under such circumstances, being usually very feeble, only a small force of colliers can be put on, and thus the out-put of coal will be proportionately small: or supposing the air to be sufficient for a large number of men, there would be no advantage in employing them, for the distance would preclude the delivery of any large quantity of mineral at the level's mouth, and the coal could not be removed from the workings as fast as loaded. The impossibility of obtaining a large supply of mineral from the generality of levels, causes the inevitable necessity of having numerous openings, for the purpose of getting a sufficient and regular supply where extensive works are carried on; thus spreading the mineral workings over a large surface of ground, and at all degrees of elevation, and necessitating the employment of a large amount of capital in the various openings, and in tramways and inclines for connecting them with the works, much enhancing the difficulty and expense of supervision, cost of haulage, and damage to surface.

The apparent superiority of level workings to pits usually gains some strength from the fact that to most non-professional persons a coal-pit is not an inviting place, and a vague feeling of danger arising from descending the grim chasm, and of explosion or other accident when down, deters many interested parties from making any personal examination, whereas they would not so much object to walking a short distance into a level. But it must be remembered, that many of the sad accidents of late years have occurred in levels, and, generally speaking, it may be considered that pits are usually better ventilated, and in all respects safer, than levels: and are on the whole worked with more economy.

The out-put of coal from a level is considered good if it amounts to 60 or 80 tons per day, and as being remarkably great when it amounts to double the latter quantity, in fact, in numerous instances, it would not amount to more than 40 or 50 tons per day. Now a pit will turn out easily, from a single shaft, 300 tons per day, and double that quantity if required, in the day of 12 hours; and the whole being delivered at one spot, no haulage for the purpose of concentrating such a quantity of mineral is required, as would be the case where the same quantity of coal has to be procured from a number of levels. The outlay incurred by some undertakings in mineral openings straggling over a large area of ground, and necessitating the construction and maintenance of great lengths of tramway, inclines, engines, &c., is sufficient in itself to effectually prevent business being carried on with a profit to the adventurers. In working by pits a range of mineral may be procured in every direction around the shaft; and when one bed is exhausted the pits can be deepened so as to open up another, and the mineral will still be landed at the same spot. In working minerals by a drift driven into a hill-side, they can usually only be procured from one direction, and it is often the case that the whole must be brought out at one opening or level mouth, however great the distance of the workings may happen to be from such opening; but it usually happens where minerals are worked by pits, that there is the opportunity of sinking fresh shafts from the surface to carry on the workings, as soon as their distance from the original shaft may be inconveniently and unprofitably great. The further distance a level is driven under a hill the more difficult is it to provide good ventilation: the deeper the shaft the better, with judicious arrangements, is the current of air procurable.

The quality of minerals varies very greatly; and usually it will be found more safe and profitable to incur considerable expense in opening up good minerals, than to invest capital in working those of an indifferent description, although they may be much more cheaply procured; for a good article will always command the market.

It frequently happens that owners of minerals are so short-sighted to their own interests, as to prefer leasing minerals to any parties who may offer a high price, instead of making arrangements with respectable parties, on such terms, that they may be enabled to obtain a reasonable return for their enterprise and risk of capital. The interests of the lessor and lessees should be identical, but it very frequently happens that such is not the case.

It very generally happens that works are commenced in times of prosperity and excitement, when material and labour are high-priced, and they commonly change proprietors in times of depression, and get valued to the new in-comers at the then existing prices of labour, &c., so that in addition to loss that may have been sustained by the original owners during the erection of the works, and also in the time during which they may have carried them on, there is a further, and frequently heavy, depreciation, owing to the fluctuation in prices.

In starting a work in busy times there is also usually every endeavour made to get to work as speedily as possible, so as to share in the advantages of a time of highly remunerative prices: this acts disadvantageously in many ways, especially as relates to due care in the arrangements of leases of mineral, &c., which do not receive the attention their importance deserve, owing to the desire for immediately proceeding with the undertaking.

Iron and coal companies, got up by prospectus, or otherwise, on the joint-stock system, are usually projected by parties who, either as landowners, or in some other way, have interests in the affair totally separate and distinct from those of the body of shareholders, and who are speculating at the expense of others, endeavouring to grasp a share of any gain that may arise, and being totally indifferent as to the loss and suffering their proceedings may cause to those who have been persuaded into joining them, and whom they have succeeded in dazzling and deluding: and judging from foregone examples, such undertakings end in difficulty and disaster, and are usually to be carefully avoided.

Too much attention is frequently paid to the delusive views of working colliers and miners, and heavy losses have thus been incurred. Without wishing in any way to underrate the skill and judgment of this highly useful class, it is necessary to bear in mind, that from the nature of their occupation, the information they acquire is usually of so local a character, as not safely to be much depended upon, especially in connexion with the first opening up of ranges of mineral previously unexplored.

Doing business for the sake of doing business is a course of procedure to be deprecated and avoided; nothing is to be got by it—and without there is a profit to be obtained business had better not be undertaken. No business transactions are *perfectly* safe, there is always more or less of risk, and when loss is incurred in connexion with transactions upon which there is no reasonable margin for profit, it tells with destructive force.

The reckless competition and insane proceedings that often take place, in connexion with large contracts especially, are little suspected, and less known to the uninitiated, and may more properly be designated gambling than bona fide trade transactions.

Heavy contracts, and undertakings that are supposed by the general public to be highly advantageous and profitable to the parties who are so happy as to obtain them, and who are consequently the objects of envy, are often not only of but little real and substantial advantage, but are frequently the cause of irreparable losses and difficulties to those undertaking them.

Grand points for attention in endeavouring to secure success, are to undertake no more business than there is capital and ability to conduct properly; to undertake no business without a fair prospect of reasonable profit, and never to risk at any one time, or in any one line of operations, an amount of capital, the loss of which, would entail inextricable difficulty and disaster: and in order to be in a position to take every advantage of favourable circumstances as they arise, nothing is of more importance than *keeping down expenses*, such as rent, interest of money, cost of management, and other current charges. In a concern where the outlay of money has been judiciously made, and the amount sunk in works and appliances has been kept in due proportion, and the current expenses economically arranged, there is the power not only of being able to bear, with comparative ease, the pressure of adverse times when they occur,—and occur they will, and often with but little or no notice of their advent,—but there will also be the power, to a great

EDINBURGH:
FULLARTON AND MACKNAB, PRINTERS, LEITH WALK.

TN
704
G7W5

Wilkie, George
The manufacture of iron in Great Britain

Mining

PLEASE DO NOT REMOVE
CARDS OR SLIPS FROM THIS POCKET

UNIVERSITY OF TORONTO LIBRARY

[redacted]